Economic and Social Commission for Asia and the Pacific

Water Resources Journal

E/ESCAP/SER.C/126

September 1980 (Quarterly)

United Nations

Contents

	Page
Taking advantage of the water hyacinth	1
The future for remote sensing from outer space: water resources and land use	6
Satellites seek subsurface sources	9
New approach to flood control	11
Micro power: An old idea for a new problem	14
Pilot projects speed Thai decade plans	23
Rainfall depth-duration-frequency studies for Sri Lanka	26
Research and development	37
Conferences, symposia, training courses	40
Selective information section	42

The designations used and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimition of its frontiers or boundaries. The views and opinions expressed are the authors' own and do not necessarily reflect those of the United Nations Secretariat. Mention of any firm or licensed process does not imply endorsement by the United Nations.

TAKING ADVANTAGE OF THE WATER HYACINTH*

The water hyacinth (*Eichhornia crassipes*) is one of the most successful colonizers in the plant world. This free-floating freshwater plant has spread from tropical South America to at least 50 countries around the world. Japanese exhibitors who came to the 1884 Cotton States Exposition at New Orleans, Louisiana, brought along this aquatic plant because of its beautiful lavendar flowers. They had collected the water hyacinths from the Orinoco River in Venezuela. These plants were given away at the exposition as souvenirs. The water hyacinth problem in the southern United States began when many of those beautiful souvenirs from the Cotton States Exposition were tossed into drainage canals, swamps, streams and bayous. Because of the lack of insects, viruses and other natural enemies which kept this plant in check in its native environment, the water hyacinth grew explosively. This innocent gesture created a persistent aquatic weed problem which costs millions of dollars a year to keep under control.

After its inadvertent introduction into the United States, water hyacinths rampaged through Louisiana, Florida and Texas. Just 11 years after the Exposition, a massive water hyacinth colony 160 km long was discovered on the Saint Johns River in Florida, over 960 km from New Orleans. Current infestations in Florida, Louisiana and Texas cover approximately 700,000 ha of waterways and cost these three States alone over $US 11 million a year in control efforts.

In 1900, the United States Army Corps of Engineers was given the task of controlling the voracious water hyacinth. In 1902, the Corps started using sodium arsenite as a herbicide. This herbicide is a chronic, cumulative poison that is highly toxic. Eventually the carbinogenic properties of the inorganic forms of arsenic were also recognized (inorganic arsenic has been positively linked with skin cancer). In 1937, it was abandoned in favour of mechanical harvesting. After 10 years of fighting a losing battle, the Corps turned to a new herbicide, 2.4-D, a plant hormone that became available in the late 1940s. Since then, this herbicide alone has been used in an effort to control the water hyacinth. Other control measures involve biological agents, such as insects and diseases. Recently, integrated programmes using both chemical and biological control efforts have shown a greater degree of success.

Nevertheless, in many instances, the water hyacinth is able to reproduce itself faster than it can be killed off. In a celebrated observation made in Louisiana, two parent plants produce 300 offspring in 23 days, and 1,200 within four months. Under the most favourable conditions it is known that 10 plants can multiply to 600,000 and virtually carpet an acre of water in only eight months.

The main reason for the water hyacinth's ability to spread so rapidly is very simple. Its swollen petioles or leaf stalks allow it to float, thus freeing it from a terrestrial grip. The plant's leaves act as sails and, when driven by the wind, *E. Crassipes* has even been observed travelling upstream against the current.

Not surprisingly, the water hyacinth survives to this day in all the regions of the world that it has ever invaded. So far all the control methods used have proved unsatisfactory in some respect. Herbicides that kill hyacinths are available, but they all share three drawbacks: they are suspected of adversely affecting aquatic animal life; they are expensive to apply; and it is difficult to spray them efficiently.

Since warm water fosters the growth and spread of water hyacinths, tropical and subtropical regions are the hardest hit. But in northern California, New Zealand, southern Australia and Argentina, the water hyacinth is proving that it can survive equally well in temperate climates.

The water hyacinth has been an expensive nuisance in such countries and areas as Argentina, Australia, Bangladesh, Brazil, China, Egypt, India, Indonesia, Nicaragua, Pakistan, the Philippines, Puerto Rico, South Africa, the Sudan, Thailand and Zaire, to name a few. Control and eradication measures in most of these countries have been greatly hindered by the remoteness of many of the heavily infested areas and by the lack of modern technology and equipment necessary for either spraying or mechanical harvesting. Massive infestations on major waterways such as the Congo and the Nile rivers have seriously restricted boat traffic, which is the primary transportation link for agricultural products, dry goods and export materials, not to mention people. The water hyacinth also hinders commercial fishing and reduces yields from rice paddies when it invades flooded croplands. Even more serious, the water hyacinth increases water loss because of its high evapotranspiration rate. Large mats of water hyacinths are about 95 per cent liquid. This is because, for each

---

* By B.C. Wolverton, senior research scientist, and R.C. McDonald, research chemist, United States National Space Technology Laboratories, United States National Aeronautics and Space Administration, NSTL Station, Mississippi 39529, United States of America. This article is based on one which appeared in the Swedish publication *Ambio*, vol. VIII, No. 1 (1979), and was reproduced in *Water Power and Dam Construction*, vol. 31, No. 7 (July 1979), pp. 25-28.

part of solid created, the water hyacinth soaks up as much as 19 parts of water. This can have drastic consequences, especially in arid or semi-arid regions such as the Nile valley, where water hyacinths sponge up water that could otherwise be used for irrigation.

Expensive control measures have been tried. For example, in 1957 the Belgian Congo spent $US 1.5 million on an eradication programme. The Sudan has spent approximately $US 2.5 million annually since 1962. Still, the water hyacinth persists today in these countries and continues to be the major aquatic weed problem.

Although this plant has been considered an uncontrollable monster for a hundred years, its image is being changed by the United States National Aeronautics and Space Administration (NASA). The characteristics that have caused this plant to be cursed for decades make it an ideal candidate for large-scale nutrient removal and water purification. The water hyacinth shows promise for partially supplying life-sustaining functions for space stations (oxygen, food, pure water, waste treatment, etc.) in addition to providing many earthly benefits. When the highly prolific water hyacinth is put to work under controlled conditions, it can produce massive quantities of desirable products, such as high quality vegetable protein, vitamins, minerals, energy (in the form of biogas), fertilizer, chemicals and fibre. It can also purify domestic and certain industrial waste waters and produce large quantities of fresh water.

At the National Space Technology Laboratories (NSTL) near Bay St. Louis, Mississippi, the water hyacinth is being used by NASA as the principal biological agent in a relatively new and very promising concept which utilizes aquacultural techniques for treating domestic and chemical waste waters. Microorganisms are used in combination with higher vascular aquatic plants for waste treatment and water purification. This system promises to be an economical, versatile waste-water treatment method for upgrading existing conventional waste-water treatment plants or for creating the nucleus of new systems for removing organics, biochemical oxygen demand (BOD) and chemical elements (nitrogen, phosphorus, etc.) from waste water. The water hyacinth is used in conjunction with waste-water treatment for the recovery of valuable minerals from waste during the treatment process by harvesting plant biomass.

Generally, NASA's multi-faceted programme can be divided into four areas: domestic waste treatment; chemical waste treatment; growth rate and harvesting studies; and product development to utilize the tremendous quantities of biomass that can be removed daily from a lagoon during favourable growing conditions. The major findings of each area of this research programme are presented below.

1. Domestic waste treatment

In the United States, the most popular and inexpensive method of treating domestic waste water in small communities of 10,000 or fewer people is the sewage lagoon, where waste water is retained for approximately 30 to 60 days for the organic material to be biologically degraded and stabilized. The effectiveness of sewage lagoons or any domestic waste treatment facility is evaluated from the measured reduction of BOD and total suspended solids (TSS) in the waste water from the influent point to the discharge or effluent point. Removal of certain nutrients, primarily nitrogen and phosphorus, is also receiving attention to prevent the accelerated eutrophication (nutrient enrichment) of lakes and streams which receive wastewater discharge.

Facultative lagoons, the most common design, are usually from 91 to 122 cm deep and contain both aerobic and anaerobic zones. According to a survey conducted by Barsom the five-day BOD (BOD_5) and TSS of facultative lagoons averaged from 25 to 75 mg/l and from 60 to 120 mg/l respectively. Very little data are available on the effectiveness of facultative lagoons for nutrient removal. However, from the author's experience, these lagoons did not significantly reduce phosphorus and nitrogen.

Recently the United States Environmental Protection Agency (EPA) set strict maximum limits on BOD_5 and TSS of 30 mg/l each. All State water pollution control agencies can either use these maximum guidelines or impose stricter requirements on waste-water discharges, depending on the individual site situation. Proposed future EPA standards will also include nutrient limitations on nitrogen and phosphorus. Some States have already formulated nutrient regulations.

In an experiment at NSTL, the water hyacinth was introduced into an existing lagoon which consisted of only one cell and which received a relatively light organic load. During the evaluation period, the average influent BOD_5 was reduced by 95 per cent, from 110 mg/l to an average of 5 mg/l in the effluent. Also during this same period, the average influent suspended solids were reduced by 90 per cent, from 97 mg/l to 10 mg/l in the effluent. The average monthly total kjeldahl nitrogen (ammonia and organically bound nitrogen) was reduced from 12.0 to 3.4 mg/l prior to discharge, and the total phosphorus was reduced from 3.7 to 1.6 mg/l. The water hyacinths did not allow nuisance algal blooms (uncontrolled and prolific algal growth) to occur, as demonstrated by the low suspended solids. Because of the improved quality of the lagoon, no odours were emitted. The lagoon resembled a clean, fresh-water lake with abundant populations of small fish, turtles, frogs and waterfowl.

In a similar study using a secondary, facultative lagoon which received the discharge from a primary, aerated lagoon, water hyacinths also effected a significant improvement in water quality.

Neither of the above systems was covered for winter protection and the tops of the water hyacinths were damaged by frost. However, the roots were undamaged and the plants reprouted in the spring. In northern climates, prolonged freezing weather will kill the water hyacinths if the plants are left unprotected. Both of these lagoons shared another minor problem, spider mites (*Bryobia praetiosa*). This insect pest that occasionally causes minor damage to the water hyacinths can be easily controlled by spraying with an insecticide such as malathion when necessary.

Although offensive odours did not occur in these systems, this problem can become significant in lagoons which have a heavy, organic loading rate. In heavily loaded lagoons, the plants should be kept thinned out to provide oxygen from wind action and photosynthesis to the lagoon, or mechanical aeration should be supplied to keep the pond surface aerobic and free from offensive odours.

Waste-water treatment experiements using water hyacinths to upgrade treated waste water from a trickling filter plant and polishing pond system were conducted in Florida. The effluent from this system was discharged into a water hyacinth-covered test pond, in which depth and retention time could be varied. The water hyacinths grew quickly and an area-doubling time of 6.2 days was observed. This effort reaffirmed the idea that the nutrient removal capacity of a water hyacinth system is greatest during the active growth phase and is dependent on the surface area to retention time ratio.

A similar experiment was conducted in Texas, evaluating the water hyacinth's effect on treated effluent from multi-cell lagoon systems; the experiment consisted of primary treatment using aeration followed by secondary treatment with stabilization ponds. This experimental system demonstrated again that water hyacinths grown in a controlled environment can substantially reduce the level of algae, suspended solids, dissolved impurities and nutrients and produce a high quality effluent. This water hyacinth system was economical to construct and operate; it required minimal attention and little energy other than sunlight.

Several other experimental prototype water hyacinth systems are now being designed or are under evaluation. One such system is currently being designed for evaluation at San Diego, California. This system is the first to be planned for maximum fresh-water recovery. Another system designed to remove nutrients from an activated sludge plant effluent has already been installed at Coral Ridge, Florida. Preliminary results demonstrate that water hyacinths reduce the suspended solids and BOD_5 below the required mean of 5 mg/1, and reduce the nitrogen levels below the required 3 mg/1. A similar nutrient removal system is planned for Disney World in Florida to remove excess nutrients from an activated sludge plant effluent. Several small communities in southern Texas have also been granted permits to demonstrate the effectiveness of upgrading their central waste treatment systems through the controlled growth of water hyacinths.

2. Chemical waste treatment

The water hyacinth's unique survival capacity has made the permanent eradication of this plant very difficult. This characteristic was further tested in static laboratory experiments with toxic chemicals to evaluate its potential for purifying not only domestic waste water but also industrial waste water. The water hyacinth can readily absorb and concentrate heavy metals such as lead, cadmium, mercury and nickel. In a water hyacinth chemical waste system, the roots of one group of plants were found to contain 594 ppm copper, 297 ppm lead, 113 ppm silver, 164 ppm cadmium and 286 ppm chromium. Yet the plants exhibited no visible sign of toxicity. Water hyacinths can also rapidly concentrate cadmium from polluted water containing concentrations as low as 0.001 mg/1.

Other static laboratory tests were designed to evaluate the potential of using water hyacinths to absorb various organic chemicals. It was found that the water hyacinth could remove 36.4 g phenols per kg of plants in a 72-hour period, and that 281 mg toxaphene per kg of plants could be removed in 48 hours.

The potential of using water hyacinths in a full-scale chemical waste system was successfully demonstrated at NSTL. This system receives approximately 95,000 1/day of chemically polluted waste water generated from a large laboratory complex comprising photographic, general and pesticide monitoring laboratories. The two most important parameters to monitor in this type of system are the BOD_5 and chemical oxygen demand (COD), the oxygen equivalent of the organic matter in the sample that is susceptible to oxidation by a strong chemical oxidant. The over-all averages of BOD_5 and COD were reduced by 97 and 88 per cent respectively.

This system has now been in operation for several years. The saturated water hyacinths are periodically harvested and disposed of in an adjacent pit which was designed to prevent any of the heavy metals from the decayed plant material from leaching out into the ground water. This system is still effectively treating the chemical waste. It has been pennanently incorporated into the waste treatment facilities at NSTL.

3. Growth rates and harvesting techniques

Water hyacinth harvesting and productivity studies were also conducted at NSTL in conjunction

with the waste treatment studies. Three harvesters were manufactured and evaluated under NASA's vascular aquatic plant programme. These included a conveyor-chopper system which used a pusher boat to receive plants, a single conveyor which used the same pusher boat and an enlarged clamshell bucket operated by a dragline. Many other harvesters have also been designed to remove water hyacinths and other vascular aquatic plants, mostly from clogged waterways.

Growth baskets were placed in two different water hyacinth-covered lagoons to determine the annual productivity of the plant. The measured growth rates showed a direct correlation of growth rate and nutrient loading. The water hyacinths grew fastest during the months of May and June in the lagoon that received the most nutrients. The highest measured growth rate was 73 per cent weight gain per week. The over-all average growth rate from May to October was 46 per cent increase in weight per week. The maximum annual productivity was estimated to be 154 tons/ha if the plants were harvested with the objective of maintaining a maximum growth rate. If grown under the proper conditions, this annual productivity far exceeds the recorded biomass yields of any terrestrial, marine or fresh-water plant, except possibly some species of algae.

4. Water hyacinth products

Like most other plants, the nutritional quality of water hyacinths is greatly enhanced when grown in highly fertile environments. Water hyacinths grown in two heavily loaded sewage lagoons gave the following average analyses: 22.9 per cent crude protein; 2.12 per cent fat; 18.3 per cent fibre; 17.8 per cent ash; 3.65 per cent kjeldahl nitogen; and 0.87 per cent phosphorus. The leaves were found to contain a higher concentration of protein than the other plant sections. The leaf protein averaged 32.9 per cent. The quality of the protein obtained from one experimental lagoon located at Lucedale, Mississippi, was found to compare favourably with cottonseed and soybean meals. Toxic levels of heavy metals such as lead, mercury and cadmium were not detected in any of the studies when the plants were grown in strictly domestic waste treatment lagoons.

Although this nutrient-rich biomass shows great promise as a cattle feed supplement, no economical drying facility for large-scale dehydration of water hyacinths has yet been designed which will work efficiently in humid climates. This is because of the hygroscopic nature of this plant. The moisture content of the water hyacinth must be reduced from an initial value of 95 per cent to less than 15 per cent to prevent rapid spoilage. In very dry, arid countries such as the Sudan, water hyacinths will air-dry if spread in thin layers on the ground.

However, many other products can be made from water hyacinths which do not require initial drying. These products include protein concentrate for human food, organic fertilizer and soil conditioner, and biogas containing a higher percentage of methane.

Protein concentrate. This can be prepared from either the leaves or the whole plants by a simple 1 per cent salt extraction which separates the soluble protein from the pulp.

Composting. Water hyacinths can also undergo an aerobic decomposition process commonly referred to as composting in which all of the organic matter is stabilized. The water hyacinths are piled two to two and a half metres high and allowed to decompose naturally. This provides an excellent organic soil supplement for sandy soils.

Biogas. The third product, which is receiving considerable attention, is biogas. Biogas is produced from the anaerobic (without oxygen) fermentation of the substrate (in this case, the water hyacinth). The phenomenal growth rate of water hyacinths makes the possibility of producing a substitute natural gas more and more appealing, especially since the price of natural gas will continue to rise as current supplies dwindle. Biogas experiments using the water hyacinth are continuing at NSTL.

Fresh water. Another potential by-product of a water hyacinth waste treatment system, which has received little attention to date, is the tremendous quantity of pure water which can be recovered from the evapotranspiration of these aquatic plants, although there may be difficulties in tapping this potential.

NASA studies at NSTL have shown that, with properly sized systems, up to 40 per cent of the daily waste water can be recovered as pure, fresh water by collecting the water that is literally pumped into the atmosphere via the plant's leaves. To collect this pure water, greenhouse covers with special drainage pipes would need to be used over the water hyacinth-covered area. This concept of fresh-water recovery has great potential for arid regions of the would where fresh water is a valuable product and where the water hyacinth is often a direct competitor with man for the available water.

Conclusion

The hardiness and high productivity of the water hyacinth can be put to use in a controlled, fresh-water environment to remove chemical pollutants from waste water. In the process of absorbing minerals and nutrients from the water, the water hyacinth produces tremendous quantities of plant biomass which can be useful for feed, fertilizer or biogas. Great quantities of pure, fresh water can also be recovered from water hyacinth systems by covering them with greenhouses fitted with

collection devices for capturing the water vapour that is normally lost through evapotranspiration.

In this design the harvested plants are processed into either feed, fertilizer or biogas in an area adjacent to the waste-water treatment facility to minimize the cost of production. The nutrients are reclaimed from the water and returned to the environment in the form of plant biomass, and the water is restored to a state compatible with the receiving streams.

Some of the same uses can also be made of the water hyacinths that are growing in the wild in areas that are easily accessible to large harvesters. Wherever practical, removing the plants from waterways would eliminate the need for spraying and would open up the waterways for navigation, recreation and fishing; it would also keep the large mats of water hyacinths from depositing dead plant material on the bottom. The compost produced from the harvested plant material could be sold to help to defray the cost of controlling the growth of these plants.

At present, water hyacinth systems are limited to fresh-water systems in warm climates. Floating greenhouses would be necessary to cover them if they were to be used in northern climates. Another possibility of harnessing nature to clean up polluted waters in northern climates would be to survey the fresh-water aquatic plants native to these regions which possess many of the characteristics which make the water hyacinth a good biological agent for pollution removal.

The potential use of this aquatic plant for domestic and industrial waste-water treatment is just beginning to be taken seriously. Aquaculture projects using the water hyacinth appear to be a promising addition to the currently accepted waste treatment methods.

THE FUTURE FOR REMOTE SENSING FROM OUTER SPACE: WATER RESOURCES AND LAND USE*

1. Dam inventory

Following dam failures at Rapid City, South Dakota, and at Buffalo Creek, West Virgina, in 1972, at Teton Dam, Idaho, in 1976 and at Toccoa Falls Dam, Georgia, in 1977, President Jimmy Carter ordered a number of actions, including an update to a 1975 inventory of all sizable dams and a check on the safety of each deemed a possible threat. Conducting this inventory, assigned to the Corps of Engineers, was to be no small task, since the United States had tens of thousands of dams.

The conventional mode of conducting such an inventory is to check State records (if any), to check quad maps of the United States Geological Survey (USGS), where available and recent, and to check recent aerial photos, if available. Unfortunately, several States are not completely covered by such maps or photos, and/or they are not recent. Hundreds of impoundments are created every year. And the Corps' assignment from the United States Congress provided neither the time nor the money to shoot aerial photos of the entire United States.

However, one source of current data was available: Landsat satellite pictures of the United States. (The entire country is captured every 18 days by each of the two Landsats now circling the earth and transmitting data. However, cloud cover reduces the completeness of that coverage.)

NASA staff at Houston, under a contract with Lockheed Electronics, Houston, wrote a computer programme which was designed to print out an "X" or other character at the location where surface water was encountered on the magnetic tape holding the Landsat information.

Thanks to the Landsat data, the Corps of Engineers was able to identify about 10 per cent more than the roughly 50,000 dams found earlier by traditional means. The additional percentage of dams found varied radically from State to State, reports the Corps' Harry Horton. In fact, Horton notes that in Illinois the Corps identified only half the number of impoundments known to exist. Generally, Landsat can reliably pick out only those impoundments larger than 4 ha. This is because Landsat splits up the earth into "pixels" or picture elements about 6,400 sq m or 0.64 ha in area. Landsat treats each pixel as a point source of data. Thus, its "resolution" is said to be 80 m or about 260 ft.

2. Predicting snow melt runoff

For the past 50 years, the amount of spring runoff from the melting of mountain snow has been predicted in California. Data are gathered monthly by men on skis, in snow vehicles and helicopters covering 325 snow courses across the State. These methods may never be completely abandoned, says A.J. Brown of the State's Department of Water Resources at Sacramento, but two new techniques may largely replace them. The first involves the use of Landsat to show the shrinking areas of snow cover, as spring wears on. Furthermore, to measure water content in snow, the State has standardized a sensing device consisting of a 120 x 150 cm (4 x 5 ft) tank. It is made from two stainless steel sheets, placed horizontally and about 12 mm apart; their edge gap is sealed. The space between is filled with antifreeze liquid, and an assembly of four such tanks is buried under 5 cm of soil. In winter, the heavier the snow, the more it depresses the top sheet, and the higher the resulting pressure in the antifreeze. This pressure information can be sent back to headquarters by radio. Some 60 of these sensors are in use, Brown says, and it is hoped that twice that number will be in place within five years.

By combining snow-area data obtained from Landsat with water content data from the sensors, spring runoff can be predicted. In turn, this enables the State to manage water release more effectively from its many reservoirs along streams leading out of the mountains into California's Central Valley. This valley is the world's greatest centre of irrigated farming.

3. Assisting flood relief

Landsat data can be used in managing flood response programmes, says Bernie Hoyer of the Iowa Geological Survey, in the following ways:

(*a*) To help to determine in which cases a natural disaster should be declared;

(*b*) To aid in administering disaster relief (indicating where teams should be sent);

(*c*) To help to prepare crop damage estimates.

---

* By Kneeland A. Godfrey, Editor, *Civil Engineering*. Reprinted, with permission, from American Society of Civil Engineers (ASCE), *Civil Engineering*, vol. 49, No. 7 (July 1979), pp. 61-65.

Landsat is not a perfect solution for these applications. Two reasons why are explained by Clyde Renz, formerly of the Corps of Engineers' Rock Island District and now with Ashton and Schwartz, of Bettendorf, Iowa:

(*a*) Landsat can see the earth only when no clouds hide it. In the midwestern United States, flooding is most common in spring, when clouds often hide the earth. In March 1973, Renz tried to get Landsat data, but for 108 days clouds covered the land every time Landsat was overhead.

(*b*) In many cases, better resolution is needed than the 90 m or so that Landsat C can give. Thus, for this application Renz, Hoyer and others prefer aerial photos made using colour infra-red film.

4. Uses in land use planning

An interesting variety of answers come from asking several planning groups around the United States, "How useful are Landsat images for land use planning"?

(a) *Classifying land cover in wetlands*

USGS has been researching the value of Landsat to determine the location of tree and shrub species in Virginia's 600 sq km Great Dismal Swamp.

Unlike large areas of upland forest, explained biologist Pat Gammon, in this swamp big areas are not dominated by one tree species (such as the huge areas covered almost entirely by southern pine in the south-eastern United States, for example). Thus, the USGS study focuses on "plant communities" or sizable areas sharing in common certain associations of plant species.

USGS decided to use Landsat to try to identify a number of plant communities, such as cypress gum swamp, shrub wetland and mixed deciduous wetland. Apparently, Gammon concludes, many wetland vegetation associations or communities are too closely related spectrally to be separated accurately.

(b) *Identifying land cover types in a county*

Far more enthusiastic about Landsat is Mark Jaffray of the Spokane, Washington County Planning Department. The comprehensive plan was being updated, requiring a land cover/use inventory. Jaffray already had aerial photos of his 4,580 sq km county, but there were 670 separate photos which needed interpretation. This would have required a skilled, experienced person and the task would have had to be done manually. After boundaries of the various land-cover areas were delineated, the land area of each cover class would have to be computed.

Jaffray concluded that, for Spokane Country, it would be faster, cheaper and perhaps more accurate to prepare its land-cover map using Landsat, since much of the work could be done by computer. Moreover, once the land-cover map was completed, the computer-stored data used to make it could be computer-combined with other data from the same area on boundaries of school districts, water districts, drainage areas, etc., and a map of any combination could thus be plotted.

Jaffray is now deciding which 20 land-cover classes he wants (the total number of classes was set at 20 because that is the largest number of colours that can be differentiated by the eye). The computer-printed land-cover information will consist of one alpha-numeric character for each Landsat "pixel" and it will be printed to the same scale as the USGS 7.5 minute quad maps.

(c) *County 208 planning tool*

The "208" effort, the EPA regional water quality management programme, is the regulation under which non-point source pollution is to be controlled. The 208 programme is in a sense a land-use planning regulation, designed to reduce non-point pollution such as silt run-off from bare-soil construction areas, silt, nutrient and pesticide runoff from bare farmlands and runoff from impervious areas such as highways and parking lots.

In the Washington, DC area, a key goal of the 208 programme is to improve the water quality of the Potomac River estuary. Although Washington, DC, is many miles from the Atlantic Ocean, the Potomac River is a tidal estuary; as a result, the polluted water it receives from tributary streams does not flow continually to the ocean, so Potomac pollution is more costly to control.

In its regional 208 programme, the Washington, DC Council of Governments (COG) used Landsat data to identify land-cover types. Cameron Wiegand of COG explained that he had better data than Landsat for the urbanized areas of his 6,200 sq km region, but for rural areas where high-resolution land-use data were not needed, Landsat was used.

Landsat can be used to indicate rural land-cover types, which can predict land impermeability and therefore runoff rates. Thus, Landsat data were plugged into mathematical "hydrologic models" that predict pollution washoff. Hydrometeorological data and rates of generation of various pollutants depending on land-use type are among the types of data needed. The model predicts peak flows for given storms. In the past the land-cover data were obtained solely from the ground, by spot observations.

For 208 planning and hydrologic modelling purposes, Wiegand says, Landsat data are sufficiently accurate for rural uses. He cites a study by Robert Ragan, University of Maryland civil engineer, who found that a Landsat estimate of imperviousness of a sub-basin in this area was within 3 per cent (that is, 31 per cent versus 34 per cent) of the estimate obtained con-

ventionally. Wiegand does say that the contractor who did the interpretation had trouble relating the Landsat data to "ground truth". This had nothing to do with the validity of the Landsat data, but is a warning that gathering of ground-correlation data must be done correctly.

5. The value of Landsat data for hydrologic modelling

The firm CDM of Springfield, Virginia, reports these preliminary conclusions on the value of Landsat data for hydrologic modelling:

(*a*) Predictions of runoff estimates using hydrologic models with Landsat-derived land use (land cover) information as basic data are more reliable the larger the basin size, and compare well with estimates of runoff made using conventionally obtained land-use data for larger size watersheds.

(*b*) In very small basins, it is less expensive to obtain land-use (land-cover) data conventionally, but in most others, Landsat data are less expensive. On a big basin study, use of Landsat data might significantly reduce the cost of hydrologic modelling.

Under contract with NASA, CDM, in co-operation with the Corps, is currently studying the cost-effectiveness of using conventional and remote sensing techniques for watershed planning. The study compares the cost of developing land-use information for use in hydrologic studies from Landsat satellite imagery with that obtained from conventional sources (such as land-use maps, ground surveys and aerial photographs). The study also evaluates the relative accuracy, reliability and other measures of effectiveness of Landsat and of conventional procedures and techniques.

Several demonstration watersheds throughout the United States have been selected; hydrologic models using both Landsat and conventionally obtained land-use data are being applied and the results will be analysed for their cost-effectiveness.

SATELLITES SEEK SUBSURFACE SOURCES*

A prime requirement of any attempt at ground-water exploration is accurate geological maps. In many developing countries, maps are often inaccurate, incomplete or not readily available. In such cases, satellite imagery provides precise mapping of relevant geological features.

A hydrogeologist trained in image analysis can infer subsurface hydrological conditions from geological features and structures, vegetation types and distribution, streamflow characteristics, soils and soil-moisture anomalies and springs.

At the same time, the synoptic view means that entire hydrological regions can be studied, while the sequential nature of satellite imagery allows ground-water potential to be assessed through seasonal and annual changes.

Present Landsat satellites record radiation reflected from the earth's surface in four separate bands or wavelengths:

(*a*) Band 4: green light (0.5-0.6 microns);

(*b*) Band 5: red light (0.6-0.7 microns);

(*c*) Band 6: far red and near infra-red (0.7-0.8 microns);

(*d*) Band 7: near infra-red light (0.8-1.1 microns).

Thus, four black and white images are available for each target on any orbit. Band 7 is particularly useful in hydrological investigations, since incident radiation at this wavelength is absorbed by clear water, resulting in a sharp contrast between land and water. Colour images are produced by combining bands 4, 5 and 6 or 4, 5 and 7. Various images analysis techniques can then be used to extract the maximum amount of information.

Unconsolidated rocks, especially upper or shallow units, are often extensive sources of ground water in many areas of the world. Examples include: permeable sands and gravels deposited by glacial melt water; fluvial deposits along major water channels; windblown sands; alluvial fans and piedmont ranges along mountain fronts; and beach deposits. Satellite data from different seasons may show differences in vegetation cover and other surface features which enhance geological boundaries or indicate the presence of subsurface water. In crystalline rocks, faulting and jointing may cause the accumulation of ground water in the more porous brecciated zone along the fracture. Parallel fractures can provide a considerable amount of water in the large zone between them. Short faults and joints are best viewed on low-altitude, high-resolution aerial photography, but longer fractures can often only be identified on satellite imagery.

In a recent study, the Environment and Resources Consultancy of Fairey Surveys used satellite imagery in a preliminary investigation for ground water in a rangeland study area in northern Somalia. Interpretation concentrated on features including surface drainage, geology, vegetation types and density and land capability, in addition to ground-water potential. Thematic maps were produced as overlays to 1:500,000 scale satellite mosaics. Various sites were then selected for further study by aerial photography and groundwork.

The entire area of 180,000 km^2 involved the analysis of only 13 satellite frames. Full interpretation of the imagery was completed in two months, allowing a rapid supply of results in the initial stages of the survey, so more effort could be effectively concentrated on those areas identified as having ground-water potential.

Location of ground-water discharge points, whether into streams, lakes, oceans or simply as isolated springs, is another successful application of remote sensing. Collection of data on ground-water discharge areas and rates of flow by traditional field methods is generally tedious and expensive. If the initial identification of these areas is made from aerial photography or satellite imagery, exploration and evaluation is simpler and more efficient.

On aerial photographs, springs and seeps can be identified by associated specific vegetation types, both aquatic and terrestial. In addition ground water discharged from sand or gravel aquifers into the sea creates turbidity plumes which are clearly visible on colour photographs.

When a temperature difference exists between the ground water and the receiving water, thermal imagery can be used to detect spring and seeps. In 1978, Fairey Surveys used thermal imagery to locate ground-water discharge along a stretch of the Pembrokeshire coastline in south Wales. A Daedalus 1230 scanner, recording in two thermal bands (3-5 and 8-14 microns) was used. Simultaneous colour aerial photographs on a scale of 1:10,000 were taken. To enable an absolute temperature calibration to be made, the thermal infra-red

---

* Reprinted from *World Water*, vol. 2, No. 8 (August 1979), pp. 46-49.

detector recorded the radiation emitted from the ground along with the temperature of two black bodies in the aircraft used as points of reference. Detected radiation was converted in flight to a proportional electrical voltage and stored on magnetic tape. This could then be used to provide an objective and quantitative analysis of the thermal imagery. In the laboratory, geometrically corrected images could be produced by writing the data onto photographic film.

Extrapolation of temperature data over large areas from film output is difficult because the human eye cannot compare accurately such subtle density differences. Thus computerized processing of the data is used to produce a density-sliced image, with each slice representing a designated temperature range.

Density slicing is achieved by dividing the original image into a number of distinct "grey" levels, which can either be presented in black and white or in colour. Colour slicing greatly simplifies the task of the interpreter and allows the identification of known temperature values. Temperature maps showing the detailed range and pattern of ground-water discharge can be used with selected ground data to produce relationship models and estimate the amount of available water from springs and seeps throughout the region.

Satellite imagery is particularly useful in the study of spring discharges and seeps in arid or semi-arid regions, where the appearance of unusually vigorous vegetation in areas of generally sparse plant communities suggests the presence of water supplies. Study of sequential data allows the classification of ground-water discharges into ephemeral, seasonal or perennial.

Satellite imagery has the following advantages over aerial photography as a source of data:

(*a*) The larger area covered by individual satellite images greatly reduces the amount of data to be interpreted in regional studies;

(*b*) The near orthographic projection, owing to the height of the satellite, allows an easy conversion from the image to a map format;

(*c*) Satellite mosaics of regions or entire countries provide excellent reconaissance base maps;

(*d*) Satellite images are more uniform than aerial photography in the appearance of similar features in different parts of the study area, making interpretation easier;

(*e*) The apparent sharpness of boundaries on satellite imagery, because of the lower resolution, aids the classification of significant units, which often appear gradational and ill defined on ground and large-scale aerial photographs;

(*f*) The scale of the interpretation maps prepared from satellite data at 1:250,000 or smaller has proved invaluable for planning total regional water systems in relationships between different areas.

To summarize, remote sensing has been used in ground-water exploration for some years, but principally using black-and-white photography for the interpretation of geological features. The advent of thermal infra-red linescan and satellite imagery and the increased use of colour and colour/infra-red photography now provide the hydrogeologist with sophisticated tools for the assessment of ground-water supplies and basic data for the planning and management of those resources.

In the regional context a multistage procedure is the most efficient, using satellite data for the initial reconnaissance to establish the most favourable areas, followed by aerial photography and/or thermal imagery to provide the necessary, more detailed analysis and, finally, groundwork to verify the remote sensing interpretations and provide field measurements.

Analysis of geology, landforms, vegetation, soil moisture and patterns of their distribution may indicate the availability of exploitable water resources. Thus, remote sensing may be used to identify ground-water discharges and shallow aquifers and to locate favourable sites for test drilling or production wells. Ground-water exploration using remote sensing techniques must always be augmented by appropriate field observations of the identified potential sites.

NEW APPROACH TO FLOOD CONTROL*

The city of Boston suffered $US5 million in flood damage as a result of Hurricane Diane in 1955; at today's prices and level of development, the damage would be nearly $US40 million. To protect against such devastating flooding on the Charles River, the United States Corps of Engineers has taken unusual measures. In the lower portion of the river, the Corps used the traditional approach to flood protection and built a structure. Meanwhile, upstream the Corps is implementing a non-structural flood-protection programme, preserving thousands of acres of marshes and swamps along the Charles River watershed.

Two systems, two plans

Travelling downstream from its headwaters, one first sees marshes and swamps along the Charles River. Approximately halfway through the 130-km (80-mile) journey, the river banks change to a more suburban scene of scattered housing and light industry. Nearing its mouth, the river cuts through metropolitan Boston, finally emptying into the highly commercial Boston Harbour.

Just as the river's scenery changes, so too does its hydrology. The watershed has two separate hydrological systems:

(*a*) In the lower section, an estuary which was filled and developed long ago, storm runoff races across paved surfaces straight into the river, quickly raising the water level.

(*b*) In the less developed upper section, however, 8,000 ha (20,000 acres) of marsh and swamp act like giant sponges, soaking up flood water and releasing it gradually.

To match the two hydrologic systems, there are two parts of the Charles River watershed flood-control plan. In the upper section, where wetlands control flooding naturally, the plan is simply to make sure they continue to do so (by preventing development in certain wetlands). Downstream, the dam discharges flood water into Boston Harbour.

Old dam cannot handle floods

In 1910, the Commonwealth of Massachusetts' Metropolitan District Commission built a dam across the Charles River, forming the Charles River basin. The dam, a 365 m (1200 ft) long earth-fill structure whose crest is about 4 m (13 ft) above the basin level, has a navigation lock and a sluice-way. By maintaining a reasonably constant water level in the basin, the dam eliminated the extensive mud flats and noxious odours present during low tides, protected low areas from high tides and stabilized the ground-water levels in adjacent areas. During severe storms, it protected the basin from tidal flooding and discharged storm runoff through its sluice during low tide.

The basin, extending about 13.6 km (8.5 river miles) upstream from the dam, is a priceless resource because of its urban location. Conceived as a water park, most of the basin's shoreline has been preserved for public access; just beyond lies some of the world's most intensely developed and valuable real estate. More than $US1 billion of construction has taken place on land created by filling the river estuary. But the basin is vulnerable to flooding, and the dam no longer provides adequate protection. Basin flooding has become a severe problem. Contributing factors include:

(*a*) Extensive urban development;

(*b*) Extension and enlargement of storm drainage systems;

(*c*) Reduction in natural storage, caused by filling of swamps, basins and meadows.

These factors increased flood flows to such an extent that the dam was not able to discharge enough runoff following major storms. In addition, the dam's navigation lock had obsolete and inadequate gates and could not handle peak recreational boat traffic.

The Corps and its consultants, CE Maguire, Inc. of Waltham, Massachusetts, found it impossible to improve the old dam for flood control or to rehabilitate the lock. Therefore, in 1968 the Corps recommended that a new dam should be built downstream. The United States Congress approved, and construction began in September 1972 with the demolition of existing structures at the site. Construction of the new dam began in February 1974. The new dam was dedicated in May 1978 and turned over to the Metropolitan District Commission for operation and maintenance.

The new dam has contributed three major improvements to the basin:

(*a*) *Flood control.* The major feature of the dam is its pumping station, which has six 40 m^3/sec

---

* By Frank Notardonato, Project Manager, and Arthur F. Doyle, Chief, Comprehensive River Basin Section, Corps of Engineers, Waltham, Massachusetts. Reprinted from *Civil Engineering*, vol. 49, No. 6 (June 1979), pp. 65-68.

(1400 ft^3/sec) vertical-lift pumps, which will control the basin's elevation during severe storm runoff. It is especially important during high tide, when gravity sluicing is not possible because the water surface in the basin is lower than that in the Harbour, that the pumps will continuously discharge flood water into Boston Harbour.

(*b*) *Improved navigation.* The dam also has three navigation locks to replace the single lock in the 1910 dam. Two are for recreational traffic and the third, primarily for commercial vessels, is used for recreational boat traffic during peak periods.

(*c*) *Clean water.* The new locking system will also help to improve water quality in the basin. All water entering the locks during operation is pumped or discharged by gravity to the Harbour, never back into the basin. Furthermore, sluices will draw off some of the heavier brackish water already in the basin. Every time it was opened, the lock at the old dam passed polluted sea water from the Harbour into the fresh-water basin. This salt-water intrusion is one of the chief sources of pollution in the basin. It has frequently destroyed fresh-water life, which generated noxious odours as they decayed.

While the project alone will not clean up the basin, it is the key element in a pollution-control programme currently in progress. The designers of the dam were so confident of the success of the clean-up programme that they included a fish-way in the dam. This is intended to restore to the basin anadromous fish (those that leave the ocean to spawn in fresh water) such as shad, alewife, herring and smelt.

As the lower basin study was coming to an end, the Corps was given a perfect opportunity to observe the important role of the upper watershed when in 1968 a storm hit.

While runoff from the lower basin crested at the old dam within a few hours, the upstream peak took four days to reach the structure. It took a month to drain all the storm water. One stretch of the river widened from 15 m (50 ft) to 1.5 km (nearly a mile). The wetlands had done the work of flood-control structures, holding back flood waters, then gradually releasing them.

In the late 1960s, however, substantial development threatened the wetlands. Boston's second circumferential highway was already under construction. This highway would open up to accelerating growth the mostly rural countryside as far as 70 km (45 miles) from downtown Boston. As pavement and drainage systems replaced vegetation, storm runoff would become more intense, and the land's storage capacity would decrease. This unchecked growth would increase upstream flood damages and threaten the safety of downstream residents.

The Corps decided that the surest way to save the 8,000 ha of wetlands and pre-empt the flood threat that their development posed was to buy them; however, preserving all those swamps and marshes would be too restrictive for orderly basin growth. The late Elliot Childs, Chief of the Corps Hydrology Branch at the time, determined that serious increases in future flood stages would be prevented by preserving only the most critical areas. Childs found that 4,000 ha, half the total, had major flood-water retention capabilities. Geographically, these areas are separate, widely distributed units; hydrologically, they act as a single, integrated system.

After studying the 4,000 ha in detail, the Corps selected for acquisition about 3,400 ha in 17 natural storage areas whose sizes ranged from 48 to 936 ha. For the first time, the United States Congress in 1974 approved and appropriated money ($10 million) to buy land for non-structural flood control. What followed was the Natural Valley Storage (NVS) programme.

Between 1974 and 1977, the specifics of NVS were worked out and the wheels set into motion. Hydrologists measured storage capacities and inflow/outflow characteristics of each area; engineers determined boundaries; real estate specialists searched titles, appraised land and negotiated for property.

Land acquisition

The New England Division purchased the first acreage in May 1977 and expects to finish in 1981, acquiring the wetlands according to priorities of location, storage volume and development threat.

The Corps is paying fair market value for the wetlands. Some property owners are unwilling to sell their land, however, even though they support the programme. In other cases, critical areas are owned by land trusts, such as the Massachusetts Audubon Society. In these situations, a special easement allows the owner to retain title to the property, but gives the federal government access for inspections to ensure that the land is being preserved.

Naturally, there have been questions. Many have worried about the tax revenues lost when privately owned wetlands are taken from tax roles. One community, for example, has 23 per cent of its land designated as a natural storage area. To compensate for such losses, the Massachusetts State Legislature has authorized reimbursement to affectedc cities and towns.

Once the land is in the public domain, the Corps maintains ownership, but not management. Through a lease agreement with the Corps, the Massachusetts Fisheries and Wildlife Division will manage the areas, enforcing laws, stocking fish and improving habitats.

In January 1979, the Charles River again experienced near record flooding. The new dam's pumping station successfully discharged the flood waters from the basin, preventing an estimated $14 million in damages. And the wetlands once more performed effectively, first storing the flood waters, then gradually and safely releasing them. The wettest January on record has demonstrated that not only is this dual approach to flood-plain management unique, but also that it works.

MICROPOWER: AN OLD IDEA FOR A NEW PROBLEM*

Introduction

In most countries there are two main options for meeting the demand for electricity: (*a*) to build large capacity plants corresponding to the requirement of large towns and industries, (*b*) to build small hydro-plants alongside the larger ones, so as to develop all the resources available.

Many factors have led to more attention being focused (both at government and consumer level) on the second option, i.e., the development of mini hydro schemes in a number of countries, including France. These are the ever increasing price of fossil fuels, shortages caused by natural disasters or wars and the desire to save foreign currency and still ensure reliable supplies.

There is no official definition for micro or mini power-stations or for mini hydro; there is not even a consensus on the terminology, because for many countries it is a new concept. In France, people generally agree to use the term micro power-stations for plants of less than 2,000 kW installed capacity, or those incorporating units of less than 1,500-2,000 kW in rated capacity, whatever the head may be. Others associate the concept of small hydro with low head, i.e., less than 6 m or even 13 m in height. Engineers at Electricité de France (EDF) and French manufacturers generally agree with the first definition.

In France, mini hydro has always been favoured, to a greater or lesser degree, so that a large number of mini power-stations are currently in operation. EDF operates 147 micro power-stations having 277 small sets between 50 kW and 2000 kW. Their aggregate installed capacity is 87.4 MW and they generate 402 GWh yearly. Heads vary from 1.5 m to 620 m, and design flow from 80 litres per second (1/sec) to 36 m^3/sec (see table 1).

Independently owned generators in France existed in 1977 at 913 plants producing 1,588 GWh with a total installed capacity of 303 MW.

For France as a whole, 1,060 micro power-stations together produce 390 MW and generate 1,990 GWh, representing 1 per cent of the current capacity of the French system (average plant factor: 0.57).

Development of micro power-stations is continuing in France and has provoked particular interest since the start of the oil crisis in late 1973. One French manufacturer (in France five are specialized in this field) delivered 16 small turbines in 1972 and 27 in 1977; the characteristics of these are shown in table 2. EDF commissioned two micro power-stations in 1973. The next ones were not commissioned until 1977 and 1978, and three others were being constructed for service in 1979-1980. Therefore during the period 1970-1974, when oil costs were lower, the attention of EDF planners was directed away from both mini and even larger capacity hydro. The oil crisis brought about a significant change.

In France, the development of mini hydro schemes is mainly undertaken by private organizations or individuals rather than EDF. The reason is that among the sites still available for development or renewal, 68 per cent offer a head between 1 and 4 m and, for economic reasons, EDF usually only deals with sites having heads of over 6-7 m. On the other hand, people who were once developing only mini hydro schemes with a view to selling electricity to EDF (which they are obliged to do by law) are now interested in producing energy from their own schemes, for example, to heat their homes. Low interest loans, fiscal incentives and the escalating price of electricity greatly encourage this search for a private electricity supply; also, if private individuals are able to build cheaper civil works than a large company such as EDF, developing heads under 6 m becomes attractive. There is such a great prospective market in this field that some French manufacturers have finalized four types of siphon units for different discharge conditions, suitable for heads between 1 and 4 or 5 m (figure I). For one manufacturer, discharges range between 190 1/sec and 250 1/sec, giving an output between 5 and 39 kW; it was planned to increase this figure in 1979 to 150 kW. Among prospective clients are hotels, small workshops and sawmills.

Developing countries are also interested in mini hydro. The main reason for this is not the concern for developing natural resources, but for supplying remote regions that will never be connected to a major distribution network, or only in the very distant future. However, the potential required to improve the standard of living of the population of these regions already exists there.

The diesel engine and gas turbine have provided many localized power sources so far, but price increases for fossil fuels now make them less attractive. If there are small rivers in the area, however, the hydroelectric micro power-station could provide an economical alternative.

---

* By J. Cotillon, Chargé de mission, Direction de l'Equipement, Electricité de France, 3 rue de Messine, 75008 Paris, France. Reprinted, with permission from *Water Power and Dam Construction*, vol. 31, No. 1 (January 1979), pp. 42-47.

Table 1. ESF micro power-stations

Number of plants	Number of sets	Generator	Head (m)	Design discharge (m^3/s)	Unit rating (kW)	Aggregate installed capacity (MW)	Output (GWh)
Micro power-stations with a capacity of less than 2 MW							
Bulb sets							
34	63	synchronous	1.5 to 18.3	3 to 36	<500	0.2	0.9
		induction				9.4	41.2
2	6	synchronous	4 to 7	8 to 15	>500	0	0
		induction				0.8	5.0
2	5	both	2 to 4.3	9 to 26		0.8	3.9
38	74		1.5 to 18.3	3 to 36		11.2	51.0
Other sets							
84	161	synchronous	1.7 to 620	0.08 to 29	<500	48.2	222.5
		induction				2.5	13.6
25	42	synchronous	4 to 351	0.2 to 29	>500	25.2	113.5
		induction				0.3	2.0
109	203		1.7 to 620	0.08 to 29		76.2	351.6
Total: 147[a]	277[a]					Total: 87.4	402.6
Micro power-stations with a capacity of over 2 MW							
Bulb sets							
5	15	synchronous induction	2.7 to 11.5	3 to 75	<500	2.1	8.5
						3.5	23.0
10	44	synchronous induction	5 to 16.5	4.5 to 8	>500	0	0
					41.5	105.2	
15	59		2.7 to 16.5	3 to 75		47.1	136.7
Other sets							
21	26	synchronous induction	14.9 to 562	0.15 to 7	<500	9.2	36.8
						0.2	1.5
53	125	synchronous induction	7 to 448	2.1 to 33	>500	110.7	482.9
						2.9	18.9
74[b]	151[b]		7 to 562	0.15 to 33		123.0	540.1
Total: 89	210					Total: 170.1	676.8

a/ This figure includes 15 small units discharging compensation water from a reservoir down to the river, the main power station being located farther downstream, at the end of a diversion tunnel or canal. They are taken into account for 15 plants.

b/ These figures include: 10 plants with some units less and others more than 1,500 kW in capacity for normal operation; 10 plants housing a small unit for compensation water discharge; and 15 plants housing 18 auxiliary units for plant consumption. Their output is not taken into account. The number of plants housing only units less than 1,500 kW has therefore to be reduced by 35.

Table 2. Small turbines delivered by one French manufacturer

Year	Number of turbines delivered				Rating	Total capacity	Head
	Total	Kaplan	Francis	Pelton			
1972	16	6	8	2	11 to 1 340 kW	6 324 kW	3 to 160 m
1973	16	6	7	3	4.2 to 1 890 kW	7 808 kW	
1977	27	3	19	5	33 to 3 250 kW	24 128 kW	1.6 to 550 m

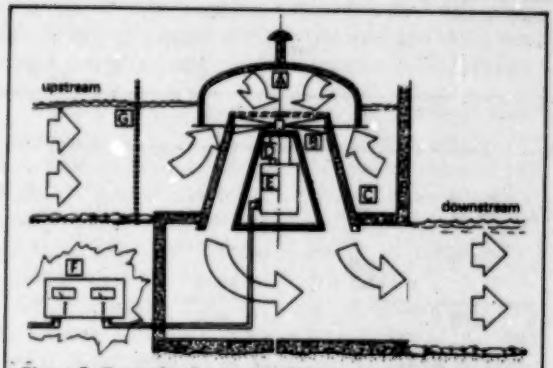


Figure I. Example of a recent siphon arrangement, showing: (a) draft tube; (b) turbine; (c) diffuser; (d) step-up gearing; (e) generator; (f) electronic governor (pressure and frequency); and (g) trashrack

Some countries, such as Indonesia and Brazil, already are or will be going ahead in this field. However, in Brazil it is worth noting the "Amazon dilemma". Many villages there are supplied by small diesel plants. Electrobras, the Brazilian State-owned electricity authority, wants oil consumption to be reduced. Large-capacity hydroplants, such as Tucurui on the Tocantins River, are being built on the main tributaries of the Amazon River, but it is not practical to route distribution lines through the Amazonian forest from these plants or from the main transmission lines.

Independent supply remains a necessity. But, in the development of mini hydro, another problem arises: on the tributaries or subtributaries there is plenty of water, but no significant head. Alternatively, when sufficient head is available, large variations in water levels (over 10 m) occur, creating design problems; on smaller subtributaries, head may be available, but without enough flow all the year round.

1. Advantages of micro hydropower stations

In addition to the advantage of having a free and inexhaustible energy source, the micro power-stations can be built quickly. The civil works are simple and can be built using local labour. There is no need for long transmission lines because output is consumed near the source, and the working life of the machines (up to 40 years) is much longer than for diesel generators or gas turbines. Operation is simple and calls for less highly skilled attention than diesel plant and full-time staff are not required for surveillance.

In addition, such small hydro schemes can have indirect benefits, such as for irrigation, either by creating a lake for a gravity system or by powering pumps.

2. Choice of site

River discharge, head and potential output, are the three main criteria to be examined when choosing a site for a micro station.

(a) *River flow.* It is essential to have the fullest information on river flow, including its seasonal variations. If flow is abundant in relation to the head and output required, there is no problem. The works are designed simply on the basis of the output.

If, however, there is insufficient flow during some part of the year, there is a choice involved in determining the rated turbine discharge. As an example of this, a rule once used in France for new micro power-stations supplying small independent networks was as follows:

(i) The month with the lowest flow was ignored, as it was accepted that the network would hardly be fed during that period;

(ii) The basic criterion was the lowest flow in the remaining months, and rated turbine discharge was taken as twice this figure;

(iii) The rated discharge had to be enough for the micro station to run at capacity for at least six months of the year.

These are only very general rules for installations with only one turbine. If several are installed, discharge through one can be equal to minimum river flow and the aggregate turbined discharge taken can be up to four times this figure.

The preceding is true for run-of-river schemes. But in some cases, there may be reason to consider creating a pond to increase capacity.

(*b*) *Head.* The head depends on the geometry of the site. Micro plants are generally classified as one of three types: low head (2-12 m); moderate head (12-100 m); or high head (more than 100 m). Head can be produced either by incorporating the power-house into the dam itself, in which case it is equal to dam height, or by providing a canal and penstock running from the dam to the power-plant farther downstream, to make use of a higher head. In fact, a penstock laid on the river bed or one of the banks can often be substituted for the canal.

Micro schemes are thus very dependent on the detailed topography of the site and local features, for example, if there are disused water mills or navigation locks.

(*c*) *Energy output.* The head and flow must be known before the output of the station can be calculated. Capacity is given by the equation

$$P = 9.8\,Q\,H\,e$$

where: P = kW generated; Q = flow in m^3/sec; and e = efficiency of turbine, generator and electrical equipment.

Generally P = 8 Q H.

3. Plant

The machines must, of course, be strongly built for reliability. They may be tailor-made to suit the individual conditions of available head and flow, but it may be cheaper to use a large number of standard and perhaps less efficient machines.

(*a*) *Turbines and generators.* The decision to develop bulb turbine technology in France was concerned with three areas: tidal power-stations; low-head schemes on large rivers; and micro power-stations.

In the last two decades, 50 micro stations have been equipped with 114 bulb sets rated between 54 and 1,185 kW; they aggregate 46.5 MW and will produce about 175 GWh (see table 1).

Some of those rated from 60-725 kW have low capacity, synchronous generators for trial purposes, with a view to having them supply independent networks. As induction units cannot be governed and consume reactive energy taken from the grid which they supply, they are only suitable for providing additional supply to a large system. On the other hand, synchronous units can be used to supply a small-capacity isolated system and 10 or 12 such units were installed by EDF as prototypes 15 years ago.

Except for isolated systems, however, asynchronous generators are generally suitable for small units supplying a large-capacity system because of their simplicity of operation and low cost (no excitation and an uncomplicated design).

Induction units may be used only when there is no problem with the reactive energy in the system. If condensors are needed to compensate totally for the reactive energy absorbed, a generator would be cheaper. If the compensation is only partial, an induction generator may still be preferable.

Bulb sets have proved to be completely successful in tidal power-stations and low-head river schemes, but it is now recognized that they are not economic for micro stations. Although they operate satisfactorily, the associated generator technology is very advanced and only specialized manufacturers can build them, which makes them costly. Special factories would be needed, but they would only be justified by a large regular market. Bulb sets have now been abandoned for micro plants in favour of inclined shaft Kaplan turbines, or horizontal shaft Kaplan turbines in offset or straight conduits [see figures III (b) and IV].

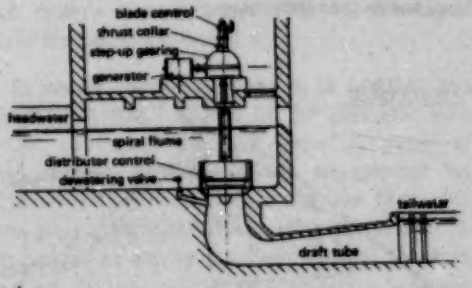


Figure IIa. Vertical shaft Kaplan turbine in an open flume

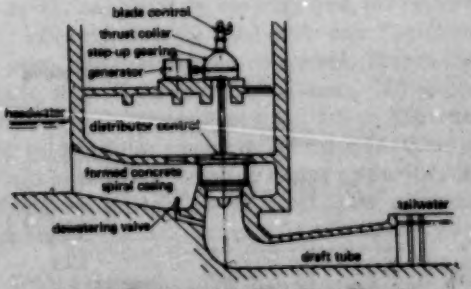
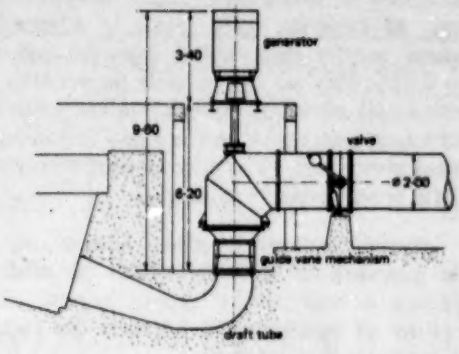


Figure IIb. Vertical shaft Kaplan turbine with a special casing



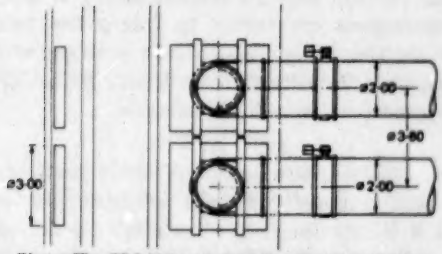


Figure IIIa. 750 MW unit at La Roche Qui Boit plant, owned by Electricité de France (EDF)

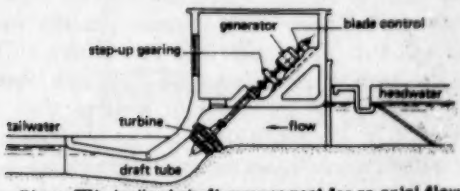
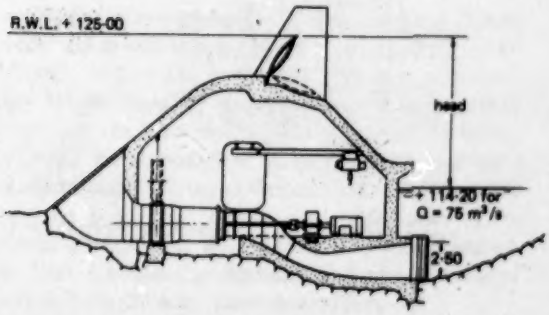


Figure IIIb. Inclined shaft arrangement for an axial flow turbine in an offset conduit



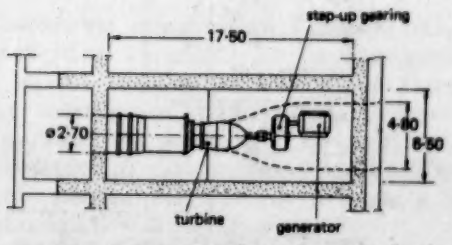


Figure IIIc. 1.9 MW unit at EDF's La Roche Bat l'Aigue plant

The choice of turbine and generator is very important: Kaplan turbines are suitable for high but variable river flow. Vertical shaft models are used for heads from 1 to 20 m with the machine in an open flume [see figure II(a)] or concrete spiral casing [see figure II(b)]. An axial flow type in an offset conduit is also possible [see figure III(a)].

Inclined-axis Kaplan machines are suitable for heads of 1-8 m [see figure II(b)]. For 1-15 m heads, a horizontal-axis Kaplan in an offset conduit [see figure III(c)] or in a straight conduit (see figure IV) can be used. The types of small units installed in France by EDF since 1973 are presented in table 3.

Fixed or movable guide vanes can be used. Under more or less constant heads, fixed blade (propeller) machines are suitable, although the means are sometimes provided for adjusting the blades with the runner stationary.

Step-up gearing is usually required for economical generator design and often to permit the use of a standard generator. With the present relationship between costs of generators and step-up gearing, the use of the latter is generally attractive only when the turbine's speed is under 300 rev/min.

For axial flow arrangements in a straight conduit (see figure IV) the bulb casing upstream of the runner does not contain the generator, but a bevel gearing connects the turbine to a generator outside the conduit. These machines are therefore not really "bulb sets". Unfortunately, they are often referred to as bulb units, even by manufacturers, and it should be pointed out that what has been said above about the excessive cost of bulb units does not concern this type of machine, which is, on the contrary, an attractive alternative to bulb sets.

The siphon arrangement is another possible configuration for a straight-flow machine when heads under 4 m and low discharge are involved. The generator can be located inside the conduit (bulb arrangement), submerged in a watertight casing under the upstream leg of the siphon (see figure V), or now, as is more often the case, placed outside, with a vertical shaft or even horizontal shaft for small-capacity machines. Manufacturers generally offer three or four sizes of standard machines for various discharges; these machines are able to operate under heads of between 1 and 4 m. Twenty years ago, EDF installed 37 siphon units with an aggregate capacity of 5,000 kW.

Francis turbines are suitable for a wide range of river flows (a few tens of litres per second to several cubic metres per second). For 2-15 m heads and fairly constant flow rates, they are placed in open flumes, the shaft being vertical or horizontal as for Kaplan turbines and, in the same way, step-up gearing is usually needed. A spiral casing setting can be used for loads

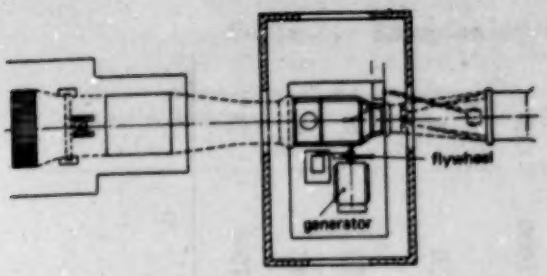


Figure IX a. Horizontal shaft axial flow turbine in a straight conduit, showing plan view

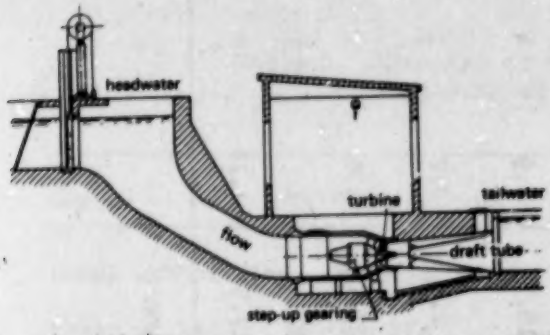


Figure IX b. Horizontal shaft axial flow turbine in a straight conduit, showing elevation

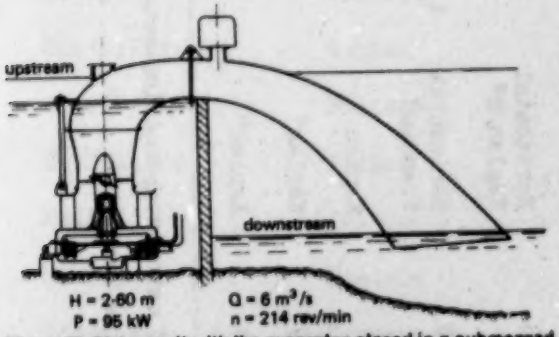


Figure X. Siphon unit with the generator placed in a submerged casing, located under the upstream leg of the siphon

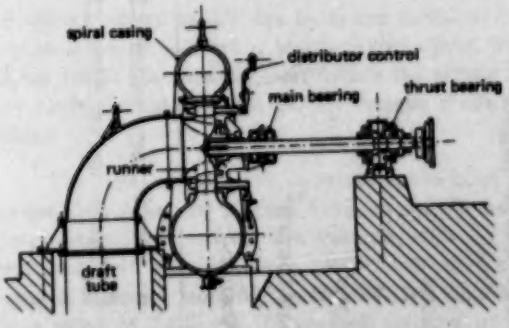


Figure XI a. Horizontal shaft Francis turbine with a steel spiral casing, with a single runner

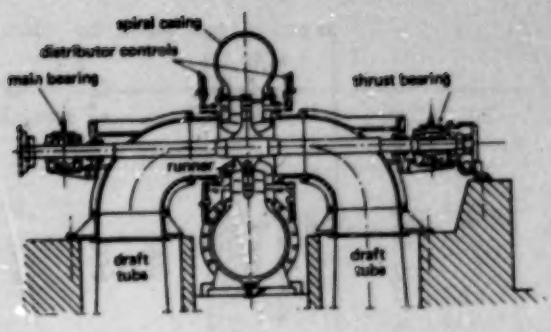


Figure XI b. Horizontal shaft Francis turbine with a steel spiral casing, with a double runner

of 5-200 m [see figure VI(a)]. Double runners [see figure VI(b)] are suitable for 5-40 m heads.

Pelton turbines are suitable for heads over 100 m with low flow rates and induction generators are used for micro power-stations supplying an interconnected network; synchronous generators are suitable for supplying an independent network.

(*b*) *Governor.* The governor must keep the speed constant, regardless of the load. Two types exist, one system controlling turbine distributor opening (balancing output to load), the other using electrical resistance to absorb the difference between the output from the fixed distributor turbine and the changing load from the network. It has been found that the second system is only economical for low-capacity plants (a few dozen kilowatts).

In isolated networks, there is, in addition to the governor, a fly-wheel located on the generator side of the shaft to exploit the high speeds developed with step-up gearing. With the siphon arrangement for a head under 4 m and small discharge, the flow control is through an air valve (linked with the tachometer), which creates an appropriate depriming of the siphon.

4. Examples of cost

As an example of the costs involved, the following French ex-work prices for fixed guide vane Kaplan sets in an open flume setting can be quoted. They include trashrack, shut-off valve, turbine, gearing, 750 rev/min synchronous generator and governor. Ten to 20 per cent should be added for transport and erection. Costs are expressed in terms of an index related to the kW, base 100 being the cost per kW of a 2,000 kW unit under a 12-m head.

Table 4 shows the advantages of a high head. When it is about 20-30 m, with a machine rating in the region

Table 3. Small units installed or being installed in France by EDF for the period 1973-1980

Name of plant	Year of commissioning	Type of turbine	Rated head (m)	Rated flow (m^3/s)	Rated capacity (kW)	Number of units	Turbine generator speed (rev/min)	Yearly output (GWh)
Fontaines d'Ugine	1973	Kaplan	15	6	0.8	1	600	5
Sous Roche	1973	Horizontal Francis	37.8	4.3	1.42	1	600	7.6
Roche Qui Boit	1977	Vertical Kaplan[a]	11.7	7.5	0.75	2	428	7.65
Roche Bat L'Aigue	1978	Horizontal Kaplan S[a]	12	18.7	1.9	4	300/1000	18
Baous	1978	Horizontal Francis[b]	114	2.2	2.2	1	750	3
Nèpes	1979	Kaplan	13	27.5	2.8	1	273	8
Strasbourg[b]	1979	Kaplan[a]	8	16	1	1	375	8
Lamanon	1980	Kaplan[a]	7.5	17.5	1.14	2	167/750	7.7

[a] Subsidiary generating unit using compensation water discharge.

[b] These units have fixed guide vanes.

Table 4. Examples of the cost of some small units

Runner diameter (m)	Head (m)	Discharge (m^3/s)	Rating (kW)	Index of unit price
1.40	2	6	100	1 500
	6	12	600	3 800
2.00	2.75	15	350	680
	4.50	17.5	650	400

Table 5. Examples of machines installed since 1965 supplying an isolated network

Owner	Turbine type	Head (m)	Discharge (l/s)	Rating (kW)
Local authorities	Francis	27	1 500	340
Paper mills	Francis	5.50	6 000	265
Flour mills	Francis	5	5 000	210
Abbey	Francis	30	800	200
Distillery	Kaplan	3.60	6 500	180
Local authority	Pelton	240	500	1 000
Irrigation	Pelton	120	16	16
Haiti	Pelton	212	66	115
Mauritius	Francis	50	2 850	1 200
Indonesia	Francis	44	3 000	1 100

of 400 kW, costs per kW can be as low as 200 to 400 (on an index of unit price) including civil works. With higher heads, the penstock cost offsets the savings on the machines and the cost per kW remains much the same.

The unit cost per kW decreases as the head increases, but also, for a given head, as the discharge (i.e., unit rating) increases. For example, with a 12-m head, the unit cost falls from 240 to 160 when unit rating is increased from 600 to 800 kW. It is only 100 for a rating of 2,000 kW. The over-all unit cost of the installation, including civil works, would therefore be between 360 and 160 for a head of 12 m, if the unit rating is between 600 kW and 2,000 kW. In such a case, the sets are economically very attractive.

5. Examples of micro plants supplying isolated systems

Table 5 summarizes the characteristics of some machines which have been installed in France since 1965 to supply isolated systems.

Another interesting example of independent network supply is the Poubara power-station in Gabon, commissioned in 1975-1976 to supply the Franceville area, although it is larger than micro plant size. It houses four 4,500 kW sets in which the Francis turbines,

running at 600 rev/min, are directly connected to the generators. The head is 40 m and each machine discharges 13.5 m^3/sec.

6. Development policy

The micro plant equipment built by French manufacturers led them to try to promote this concept between 1965 and 1970 in four countries in South America, five countries in Africa, twelve countries in Asia and New Zealand. This was in vain; although many people were interested, no orders were placed. To explain this, some of the difficulties involved in micro power-station development are outlined below.

First, electricity enterprises were not concerned with bringing electricity to remote areas. The problem was too small for them and, when it did arise, preference often went to the cheapest scheme in terms of capital cost, i.e., diesel plants. Second, there is often no single national body to deal with this problem, as there is, for example, for irrigation (such as Water Resources Development Ministries) or general development (i.e., the work done by the United States Corps of Engineers in the western United States). Yet orders have to be placed with foreign manufactures, which means that some organization of national standing is required. A maintenance organization with a small staff of technically trained people is also needed.

Unlike diesel plants, micro power-stations require no highly trained staff, servicing being confined to some monthly lubrication and emptying of self-cleaning oil filters. Cleaning trashracks requires little training. However, the machines must be inspected yearly for wear and every three, four or five years some dismantling might be required. So some minimum technical capability is required.

The development of hydro electric micro power-stations bringing electricity to remote areas in developing countries thus seems to be a political decision. The technology exists, although there are problems in areas such as Amazonia, but there are not enough implementing agencies.

In conclusion, two kinds of markets are now available for the development of micro power-stations. The first is the domestic market in developed countries, particularly if energy savings can be encouraged by fiscal incentives. The second is in developing countries, where there is definite potential in the near future, but probably not on a very large scale.

PILOT PROJECTS SPEED THAI DECADE PLANS*

While other developing nations are still coming to grips with the planning problems involved in preparing for the International Drinking Water Supply and Sanitation Decade (1981-1990), Thailand, with help from the World Health Organization (WHO), is moving ahead rapidly with pilot schemes to boost the provision of safe rural water supplies. Six districts around the country have been selected as test beds for developing appropriate water engineering technology. Simplicity and economy are the overriding criteria, with regular monitoring programmes keeping a check on contamination of newly protected wells. A specially developed PVC handpump costing just $US 25 could become the key to Thailand's success during this Decade.

Most of Thailand's rural households draw their domestic water from rivers, irrigation canals, ponds or shallow, unprotected wells. These sources are often polluted or are liable to become polluted and the threat of water-borne disease and infant mortality is ever present.

In common with other developing countries, Thailand has tended to adopt the water quality standards of developed countries and to think in terms of providing an eventual piped water supply to its 40 million people, an ambition which cannot be achieved in this century. However, the United Nations-inspired Drinking Water Supply and Sanitation Decade has been a catalyst for re-evaluation and Thailand is now making an energetic attempt to look at the problem afresh and to find the cheapest and simplest methods of supplying reliable, uncontaminated water to the rural population, which makes up 78 per cent of the national total.

At present, only 17 per cent of country dwellers (those living in villages with a population below 5,000) enjoy safe water, but this percentage is expected to increase to 25 per cent by 1981 under the current national plan. To boost this to 100 per cent in the following 10 years (the Decade target) will be an enormous task but, with the new emphasis on self-help and local involvement, it is beginning to look feasible.

A new Rural Water Supply Agency has just been formed from the seven different agencies which have dealt with rural supply programmes to date. It will take responsibility for community sanitary dug-wells and small diameter tube-wells equipped with hand pumps, large diameter tube-wells equipped with either hand pumps or power-operated pumps, and other simple solutions like rain-water collection tanks and domestic filters. This new agency works in close co-operation with a new piped water supply organization responsible for provincial supplies.

The first priority of the Rural Water Supply Agency is to try to identify areas where the simplest modifications could result in making clean, uncontaminated water available to the local inhabitants. A six-step improvement plan has been outlined with the aim of supplying the greatest number of people with clean water at the lowest possible cost. The first step will be to attempt to convert existing shallow dug-wells into sanitary covered wells equipped with hand pumps, each serving not more than 250 people. In areas where this is not practical, construction of new sanitary dug-wells will be undertaken. As simple solutions are exhausted, slightly more sophisticated systems will be tried, but the emphasis will always be on finding the simplest and most cost-effective answer, whether it is the conversion of an existing well or the construction of a large diameter tube-well equipped with a power-operated pump.

When a rational water supply development plan has been prepared for a given district, the plan will be made available to everyone involved at district, provincial and central levels. In each community, a water supply programme will be followed by a family latrine programme as part of a primary health care plan. Both programmes will be undertaken through village development committees and it is planned that, whenever possible, villagers will provide free labour and materials.

The health department has selected six districts of varying sizes, in different parts of the country, as pilot areas for concentrated effort in developing water supplies and sanitation. Experience gained in these districts will help in identifying problems and finding solutions when the pilot scheme comes to an end and the nation-wide water supply and sanitation project starts up in 1982.

A miniature solution is being implemented as a pilot project in Hang Chat, Lampang province, about 600 km north of Bangkok. The Thai Government, assisted by WHO, has made a detailed survey of 120 villages and a hydrologist has inspected all water sources in the area.

Some strange discoveries were made. For example, in one village with 100 wells only 6 wells were used for drinking. Once the region had been mapped and water resources identified, a plan of work was prepared to ensure that all sources came up to standard.

First, checks were made to see if wells dried out during the dry season; then a simple improvement plan

---

* Reprinted from *World Water*, vol. 2, No. 5 (May 1979).

was started. Under this plan, every well must be covered and equipped with a hand pump, the area around it must be protected from, for example, grazing cattle, and tests must be made for *E coli* before it is considered "safe".

With the exception of one institution, there are no piped water supply schemes in Hang Chat, and health surveillance of drinking water will be based on routine tests for *E coli*, nitrites, or free ammonia. The testing programme envisaged is: (*a*) once a week during the first three months after construction; (*b*) once a month from the fourth to the ninth month after construction; and (*c*) once a quarter thereafter. It is assumed that 35 new sources will be developed each month throughout the 18-month project period.

Each positive test result will mean immediate sanitary inspection of the source and elimination of the contamination. While WHO international standards for drinking water may not be met on all occasions, it is recognized that these are not necessarily applicable to rural conditions, and pilot projects make use of part of the standard multiple tube test to determine the presence of *E coli*.

On the "ladder" of solutions it was discovered that, out of 630 wells in Hang Chat which would need to be upgraded, only 29 would have to be small diameter tube-wells. No immediate need for large diameter tube-wells was established. The experts emphasize that this is not necessarily typical of the whole of Thailand (in the north-east, for example, water is more scarce) but it is regarded as highly significant.

With international co-operation, the Government is supplying hand pumps to villages in the project district. WHO, the United Nations Development Programme (UNDP) and the United Nations Children's Fund are all involved in the scheme and PVC hand pumps costing $US 25 each are being provided. In the first two villages, the implementing division of the Ministry converted one well, showing the villagers how to convert other wells to the same standard.

The success or failure of the Water Decade on a national basis hinges on local co-operation and individual understanding of the advantages of a clean water supply. If Hang Chat proves to be typical, Thailand standards a good chance of meeting the objectives of the Decade. Co-operation between the villagers and the Government has been good, and once people have been shown how to take care of a well they make a concerted effort to keep up the standard. Consideration is being given to establishing hand pump manufacturing units in the villages, but for the time being the local health care volunteers are the contact with villages for development and maintenance of wells.

In Hang Chat, 54 per cent of households have latrines (the national average in rural areas is 30 per cent). A family latrine programme is being developed in tandem with the fresh water supply programme, with the Government encouraging families to build either a pit latrine or a water-sealed latrine, which eliminates danger from flies.

The Government does not provide grants for this project, but a scheme whereby householders or villages could borrow moulds to manufacture water-sealed latrines is being considered. The Sanitation Division of the Department of Health is responsible for the implementation of the rural sanitary excreta disposal programme which is well established.

UNDP is assisting the pilot project in Hang Chat and in Chana, Pak Thong Chai and Samoeng districts, in support of the primary health care programme, and in July 1980 the effectiveness of measures taken in these pilot project areas will be evaluated and recommendations made for their use in remaining districts of the country.

This core project will lay a foundation in all Thailand's rural areas for the solution to the problems of access to safe water, the sanitary disposal of excreta, food sanitation, and the health surveillance of drinking water by the development, trial and evaluation of appropriate methods and technology.

One of the most important aspects of the project is the hydrogeological survey which will be carried out nationally and which will provide information on which the programme of the Drinking Water Supply and Sanitation Decade in Thailand will be based. Six hydrogeologists were appointed in 1979 and it is intended that they will be trained as instructors and will in turn train other hydrogeologists, until a full complement of 60 can be mobilized.

A key factor for consideration by the hydrogeologists is the preservation of ground-water supply, which could be depleted if there is indiscriminate mining. Poorly supervised wells stand a good chance of contaminating the ground water and irrigation demands may endanger future ground-water supply.

In the relatively dry north-east, deep ground water is highly saline, but aquifers with good quality yield of 40 to 150 litres/min exist at depths of 20-50 m.

Under the North-east Rural Development Programme, 4,000 tube-wells are being sunk for village water supplies and, in areas where the ground water is unusable, small dams and ponds are being constructed.

The Australian consulting firm, Snowy Mountains Engineering, is supervising the project, due to be completed by 1982, and equipment and technical assistance is being provided by the Accelerated Rural Development's Water Resource Centre.

Wherever the ground-water quality is acceptable, hand-pump operated tube-wells will be installed under

the project and 50 small drilling rigs have been purchased from Horwood Bagshaw of Australia.

The most severe water shortages in the region are found in small villages with populations of about 600 or less, and 2,000 villages have been identified as being in urgent need. Out of 565 wells drilled, 482 wells have been found to have fresh water, 50 have been saline and 33 day.

Part of the project calls for further investigation of irrigation water, and irrigation trials are being conducted under the auspices of the Ministry of Agriculture and Co-operatives. It is hoped that, as Thailand develops the manufacturing capability of its own pumps, they will become cheaper and people will be able to install pumps for small-scale irrigation.

The World Bank estimates that 25 per cent of Thailand's population falls below the poverty level and there is clearly an urgent need to improve standards of living, starting with primary health and basic nutrition.

The Government is making an all-out effort to plan for the Drinking Water Decade, but help is clearly needed from bilateral and international funding sources.

While Thailand is a developing country in economic terms, it is not a "developing" country in terms of skills and expertise. Within the schools and universities, technical colleges and government departments are many highly trained, articulate specialists and engineers with the knowledge to implement a pragmatic water supply and sanitation programme.

RAINFALL DEPTH-DURATION-FREQUENCY STUDIES FOR SRI LANKA*

Introduction

Very few rainfall depth-duration-frequency (DDF) relationships have been developed for Sri Lanka, largely owing to the lack of suitable rainfall records. The objectives of the present study have been to develop rainfall DDF relationships for: (*a*) the individual stations for which data were available; and (*b*) the whole of the country, on a regional basis, for the immediate use of design engineers.

Sri Lanka is a pear-shaped island situated in the Indian Ocean, north of the equator and off the southernmost tip of India (see figure VII). It lies between latitudes $5^{o}55'$ and $9^{o}50'$N and longitudes $79^{o}42'$ and $81^{o}53'$E. The total surface area of the country is 65,635 km^2 and its greatest length from north to south is 430 km.

The island consists of a central massif sloping on all sides from Pidurutalagala peak (2,528 m) to the sea. In this descent, three terraces form plateaux of different altitudes. The hydromorphic pattern of rivers is a function of relief and structure and is clearly revealed where the rivers form a radial pattern from the central mountains.

The climate of Sri Lanka is classified as tropical monsoon, a wet and dry climate but with only a brief day season, according to Koppen's classification of climates (Boucher 1975). In Sri Lanka, it is primarily the rainfall that determines the nature of the vegetation. Where the mean annual rainfall exceeds 3,180 mm, the most luxuriant vegetation exists – the true equatorial forest, or wet jungle. At the opposite extreme to the wet forest is the dry jungle, or scrub. This type occurs in areas with rainfall below 1,250 mm. In the flat coastal areas are found the palm trees which characterize the tropical environment of the island.

The mean annual temperature is around $27^{o}C$ in the lower areas and betwen $16\text{-}21^{o}C$ in the mountainous country, but there are marked variations in climate between one part of Sri Lanka and another. Noticeable features everywhere are the small annual range of monthly mean temperatures and pressures, while the diurnal range of temperature is largely a function of the seasonal winds, resulting from the monsoons (south-west and north-east).

Rainfall, generally heavy, is unevenly distributed and is the only form of precipitation. Fundamentally, it is of the convectional type, with the monsoons dominating during their respective seasons. The normal period of the south-west monsoon is May-September and of the north-east monsoon, November-March. During the transitional months of October and April, convectional rains may be generated by the difference in temperature between sea and land.

Mean annual rainfall varies between 890 mm and 5,715 mm over the island. There are two recognized zones, the wet zone, with an average annual rainfall of 2,870 mm, covering approximately the south-west quadrant of the island, and the relatively dry zone with an average annual rainfall of 1,650 mm which covers the rest of the island. During the south-west monsoon, Colombo (the capital city) and the south-west quadrant are deluged for nearly four months, while on the other side, the dry zone basks under the sun and sometimes completely dries out. During the north-east or winter monsoon, the dry zone usually gets more rain than in the season of the south-west monsoon. However, the winter monsoon, with a continental land wind, only gains moisture from the Bay of Bengal. It is therefore known as the "dry" monsoon as, in general, rainfall quantities are low in comparison with those of the south-west monsoon.

DDF studies of rainfall in Sri Lanka were carried out on data available from 19 stations. The stations are spread over the island (see figure VII) and should give a fair representation of the varied rainfall over the country.

Historical records of annual maximum rainfall depths in inches with 3-, 6-, 12- and 24 hr durations for the 19 stations were available. The lengths of these records varied from 8 to 24 years: table 6 summarizes the available data.

These data were extracted from records of autographic rain-gauges maintained by the Irrigation Department of Sri Lanka, which is responsible for all hydrological activities in the country. The autographic gauges are of standard types (e.g., Dines tilting siphon, or tipping bucket) with a 127-mm diameter orifice. Autographic rain-gauge stations are usually selected with care and a high standard is maintained in the collection and compilation of records. The available data were thus assumed to be of sufficiently high quality not to warrant correction.

---

* By Vanniasingam R. Baghirathan, Sir William Halcrow and Partners, and Elizabeth M. Shaw, Department of Civil Engineering, Imperial College of Science and Technology, University of London, London SW7. Reprinted, with permission, from *Journal of Hydrology*, vol. 37, No. 3/4 (May 1978), pp. 223-240.

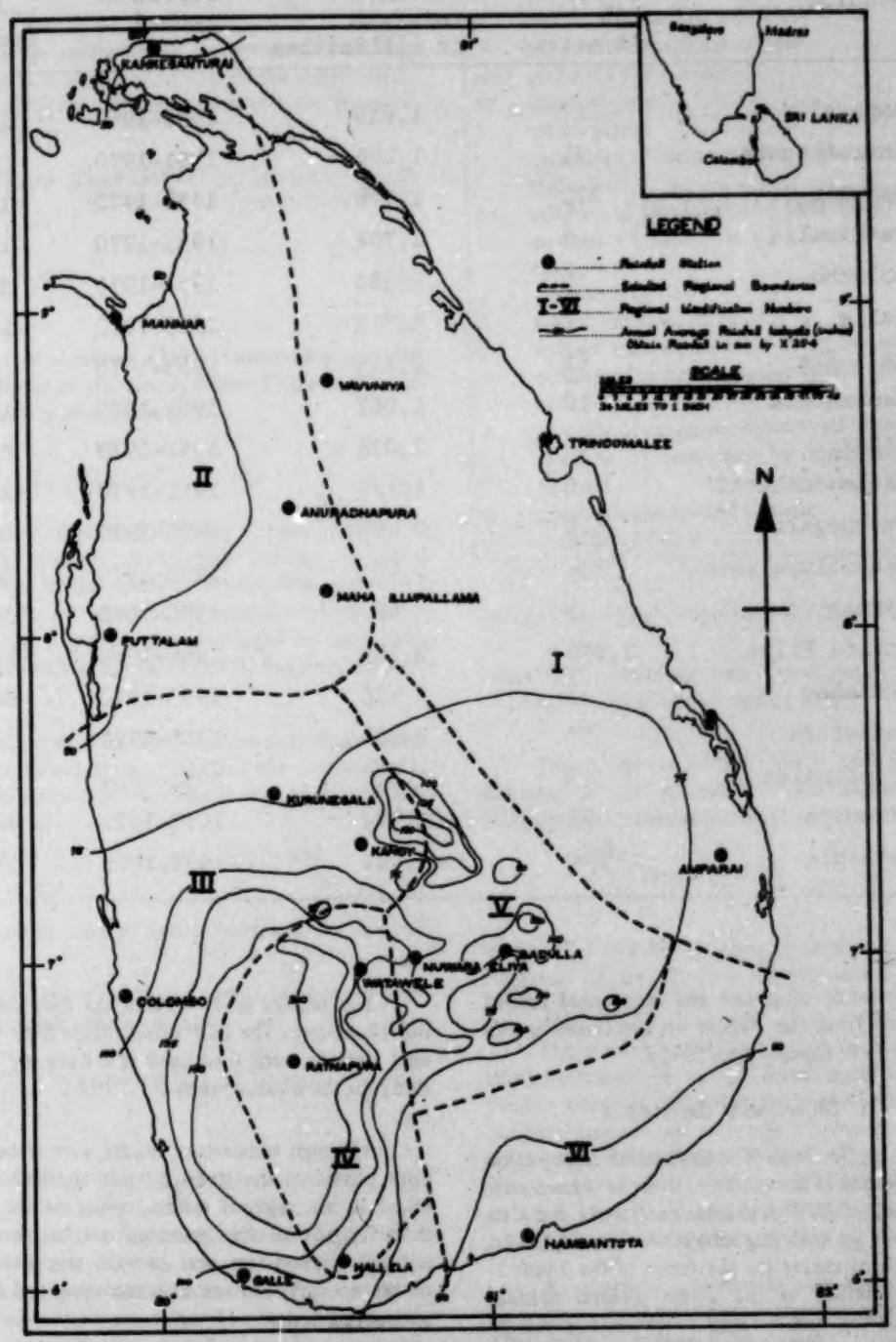


Figure VII. Sri Lanka: general locality of rain-gauge stations and of regions I – VI

Table 6. Details of stations utilized for study

Station	Height above MSL in metres	Annual average rainfall in millimetres	Period of record	Total period (years)
(1) Amparai	27	1,880	1952-1964	12
(2) Anuradhapura	91	1,448	1951-1970	20
(3) Badulla	671	1,778	1954-1970	17
(4) Batticaloa	6	1,702	1955-1970	16
(5) Colombo	6	2,388	1950-1970	21
(6) Galle	21	2,515	1955-1970	16
(7) Hali-Ela	61	2,515	1963-1970	8
(8) Hambantota	18	1,067	1954-1970	17
(9) Kandy	509	2,032	1951-1970	20
(10) Kankesanthurai	6	1,727	1951-1970	20
(11) Kurunegala	116	2,083	1955-1970	16
(12) Mahaillupallama	134	1,473	1953-1970	18
(13) Mannar	3	967	1956-1970	15
(14) Nuwara Eliya	1,899	2,159	1946-1969	24
(15) Puttalam	3	1,118	1953-1970	18
(16) Ratnapura	37	3,886	1955-1970	16
(17) Trincomalee	9	1,727	1951-1969	19
(18) Vavuniya	98	1,499	1957-1970	14
(19) Watawela	994	5,461	1937-1960	24

The statistics of annual and monsoonal rainfall were obtained from the *Report on the Colombo Observatory for 1976* (Anonymous 1972).

1. Objectives of the study

Owing to the lack of long-duration autographic rain-gauge stations in the country, there have been only limited studies of DDF relationships. Brooks and Carruthers (1946), by analysing nine stations in Sri Lanka, obtained regional curves for the ratios of the 2-year 1- and 2-hour rainfalls to the 2-year 24-hour rainfall. Since the country has a fairly extensive network of daily recording rainfall stations (approximately 500) these growth factors enabled estimates of the 1- and 2-hour 2-year events to be obtained for most parts of the country. However, it is often estimates of rarer events with longer durations that are required and relationships for them are lacking.

The present study utilized the data available for the 19 stations. The DDF relationships from the individual stations were then used as a basis for a regional study for the whole country.

Although satisfactory results were obtained from both phases of the study, greater confidence is attributed to the regional results, owing to the relatively short lengths of the individual station records. The regional relationships also provide complete coverage of the country and are thus recommended for use in engineering design.

2. Analysis for individual stations

Rainfall DDF relationships for each of the 19 stations for the different durations (i.e., 3, 6, 12 and 24 hours) were developed by fitting extreme-value type-1

distributions (EV1), the Gumbel distribution, to the corresponding annual maximum series of the available rainfall data.

The density function is defined by:

$$p(x) = \exp[-\exp -(x-u)/\alpha)] \quad (1)$$

where p(x) is the probability of an event not exceeding x, and u and α are the parameters of the distribution. Equation (1) may be written conveniently in terms of a reduced variate y:

$$p(x) = \exp[-\exp(-y)] \quad (2)$$

where

$$x = u + \alpha y \quad (3)$$

By inversion of equation (2) the relationship may be written in terms of the return period T (the reciprocal of the probability of exceedence):

$$y = -\ln[\ln(T/(T-1))] \quad (4)$$

Maximum likelihood methods of parameter determination are relatively complicated and are therefore not very popular in practical applications. However, these methods are amenable to computer application and a method based on that developed by Jenkinson (1969) and described by Clarke (1973) has been adopted for this study.

The method is an iterative one and requires first estimates of the parameters to initiate the computations. The simpler method of moments is used to provide the initial estimates:

$$\hat{\alpha} = (\sqrt{6}/\pi)[\Sigma(x-\bar{x})^2/(N-1)]^{1/2} \text{ and}$$
$$\hat{u} = \bar{x} - 0.577216\hat{\alpha} \quad (5), (6)$$

where $\bar{x}$ = mean value of data sample, and N = number in sample.

The maximum likelihood estimates of α and u are obtained by solving the equations:

$$\hat{\hat{\alpha}} = \bar{x} - \left[\sum_1^N x_i \exp(-x_i/\hat{\alpha})\right] / \left[\sum_1^N \exp -(x_i/\hat{\alpha})\right] \quad (7)$$

and

$$\hat{\hat{u}} = -\hat{\alpha} \ln\left[\sum_1^N \exp\{-(x_i/\hat{\alpha})\}/N\right] \quad (8)$$

Beginning with the moments estimates (α and u) from equations (5) and (6), the first cycle of calculations of the maximum likelihood estimates yields corrections to be applied to the estimates. The iterative computations proceed until the corrections become negligible.

The standard error of estimates obtained from an EV1 distribution fitted by the maximum likelihood method has been derived by the Natural Environmental Research Council (NERC 1975) as:

Notation

List of symbols used

E	expected frequency of variable in a class interval
j	subscript of class interval
O	observed frequency of variable in a class interval
ln	Naperian logarithm
M	number of class intervals selected
N	number of variables in sample
p(x)	probability of occurrence
SE	standard error
T	return period
u	parameter of extreme-value type-1 (EVl) distribution
u	estimate of parameter u by method of moments
u	estimate of parameter u by maximum likelihood method
x	discrete variable
$\bar{x}$	arithmetic mean of variable
y	reduced variate related to return period
α	parameter of extreme-value type-1 (EVl) distribution
α	estimate of parameter by method of moments
α	estimate of parameter by maximum likelihood method
χ	chi of the chi-squared statistic
π	constant, 3.14159

$$SE[x(T)] = [(\alpha^2/N)(1.11 + 0.52y + 0.61y^2)]^{1/2} \quad (9)$$

where x(T) = estimate with T-year return period, and y = reduced variate corresponding to T.

The χ^2 goodness-of-fit test is used to gauge the adequacy of the derived EV1 distributions. The χ^2 goodness-of-fit index is given by:

$$\chi^2 = \sum_1^M (O_j - E_j)^2/E_j \quad (10)$$

where M = number of class intervals, O_j = observed frequency in the jth class interval, and E_j = expected frequency in the jth class interval.

The level of significance can be obtained from tabulated values of the χ^2 distribution corresponding to M – 3 degrees of freedom (since the EV1 distribution has two parameters). Although there are no theoretical rules to guide the choice of M, NERC suggests that for sample sizes between 20 and 29, five class intervals be used. This recommendation was adopted for the individual station analysis.

A computer programme was developed for the analysis of the 19 individual stations which performed the following functions:

(*a*) Fitting an EV1 distribution to the annual maximum series using the maximum likelihood method;

Table 7. Fitted rainfall depth-duration-frequency relationships for the individual stations

Station	3-hour	6-hour	12-hour	24-hour
Amparai	x = 2.70+0.957y	x = 3.261+1.135y	x = 3.795+1.378y	x = 4.527+1.769y
Anuradhapura	x = 2.756+0.670y	x = 3.152+0.807y	x = 3.156+0.810y	x = 3.458+0.963y
Colombo	x = 2.885+0.709y	x = 3.551+1.084y	x = 4.185+1.121y	x = 4.998+1.562y
Badulla	x = 2.006+0.548y	x = 2.399+0.530y	x = 2.621+0.677y	x = 2.857+0.928y
Batticaloa	x = 2.695+0.875y	x = 3.078+1.015y	x = 2.721+1.314y	x = 4.404+1.995y
Galle	x = 2.975+0.874y	x = 3.545+0.828y	x = 4.069+0.915y	x = 4.208+0.999y
Hali-Ela	x = 2.886+0.990y	x = 3.465+1.484y	x = 3.822+1.666y	x = 4.231+1.936y
Hambantota	x = 2.448+0.789y	x = 2.995+0.809y	x = 3.177+0.824y	x = 3.521+1.158y
Kandy	x = 2.510+0.778y	x = 2.899+0.807y	x = 3.102+0.860y	x = 3.297+0.754y
Kankesanthurai	x = 2.140+0.902y	x = 2.670+0.996y	x = 3.289+1.015y	x = 3.773+1.419y
Kurunegala	x = 3.029+0.944y	x = 3.682+0.699y	x = 4.042+0.607y	x = 4.192+0.761y
Mahaillupallama	x = 2.973+1.144y	x = 3.334+1.079y	x = 3.353+1.141y	x = 3.650+1.392y
Mannar	x = 2.136+0.598y	x = 2.461+0.786y	x = 2.774+0.931y	x = 3.343+1.424y
Nuwara Eliya	x = 1.668+0.428y	x = 2.174+0.543y	x = 2.698+0.745y	x = 3.054+1.021y
Puttalam	x = 2.347+0.621y	x = 2.669+0.682y	x = 2.825+0.720y	x = 3.198+0.805y
Ratnapura	x = 3.165+1.029y	x = 3.920+0.848y	x = 4.386+0.790y	x = 5.007+1.015y
Trincomalee	x = 2.813+0.987y	x = 3.420+1.231y	x = 3.973+1.326y	x = 4.725+1.375y
Vavuniya	x = 2.843+0.783y	x = 3.403+0.932y	x = 4.042+1.390y	x = 4.743+1.983y
Watawela	x = 2.374+1.019y	x = 3.681+1.429y	x = 5.055+1.881y	x = 6.944+2.554y

Table 8. Rainfall depth-duration estimates for the individual stations for selected return periods

Station		Rainfall (inches) (including ± 2 standard errors)																			
		3-hour duration					6-hour duration					12-hour duration					24-hour duration				
		Return period (years)					Return period (years)					Return period (years)					Return period (years)				
		2	5	10	25	50	2	5	10	25	50	2	5	10	25	50	2	5	10	25	50
Angarai		3.05	4.14	4.85	5.76	6.43	3.68	4.96	5.82	6.89	7.69	4.30	5.86	6.90	8.20	9.17	5.18	7.18	8.51	10.19	11.43
	c.l.	0.64	1.00	1.28	1.66	1.94	0.78	1.18	1.52	1.96	2.30	0.94	1.44	1.84	2.38	2.80	1.20	1.84	2.36	3.06	3.60
Anuradhapura		3.00	3.76	4.26	4.90	5.37	3.45	4.36	4.97	5.73	6.30	3.45	4.37	4.98	5.75	6.35	3.81	4.90	5.63	6.54	7.22
	c.l.	0.36	0.54	0.70	0.90	1.06	0.42	0.66	0.84	1.08	1.28	0.42	0.66	0.84	1.08	1.28	0.50	0.78	1.00	1.30	1.52
Badulla		2.21	2.83	3.24	3.76	4.15	2.59	3.19	3.59	4.09	4.47	2.87	3.64	4.14	4.79	5.26	3.20	4.25	4.95	5.83	6.48
	c.l.	0.32	0.48	0.62	0.80	0.94	0.30	0.46	0.68	0.78	0.90	0.38	0.60	0.76	0.98	1.16	0.52	0.82	1.04	1.36	1.58
Batticaloa		3.02	4.01	4.67	5.50	6.11	3.45	4.60	5.36	6.32	7.04	4.20	5.69	6.68	7.93	8.85	5.14	7.40	8.89	10.78	12.19
	c.l.	0.52	0.80	1.02	1.32	1.54	0.60	0.92	1.18	1.52	1.78	0.78	1.18	1.52	1.98	2.32	1.18	1.80	2.32	3.00	3.52
Colombo		3.14	3.95	4.48	5.15	5.65	3.95	5.18	5.99	7.02	7.78	4.60	5.87	6.71	7.77	8.56	5.57	7.34	8.51	9.99	11.09
	c.l.	0.36	0.56	0.72	0.92	1.10	0.56	0.86	1.10	1.42	1.66	0.58	0.88	1.14	1.46	1.72	0.80	1.22	1.58	2.04	2.40
Galle		3.29	4.29	4.94	5.77	6.38	3.85	4.79	5.41	6.19	6.77	4.40	5.44	6.13	6.99	7.64	4.57	5.71	6.46	7.40	8.10
	c.l.	0.52	0.78	1.02	1.32	1.54	0.48	0.74	0.96	1.24	1.46	0.54	0.82	1.06	1.38	1.62	0.58	0.90	1.16	1.50	1.76
Hali-Ela		3.25	4.37	5.11	6.05	6.75	4.01	5.69	6.80	8.21	9.26	4.43	6.32	7.57	9.15	10.32	4.94	7.13	8.59	10.42	11.78
	c.l.	0.82	1.26	1.62	2.10	2.46	1.24	1.90	2.44	3.16	3.70	1.38	2.12	2.74	3.54	4.16	1.60	2.48	3.18	4.18	4.82
Hambantota		2.73	3.63	4.22	4.97	5.53	3.29	4.21	4.82	5.58	6.15	3.48	4.41	5.03	5.81	6.39	3.93	5.26	6.13	7.23	8.04
	c.l.	0.46	0.71	0.91	1.08	1.39	0.46	0.70	0.90	1.18	1.38	0.48	0.72	0.92	1.20	1.40	0.66	1.02	1.30	1.68	1.96
Kandy		2.80	3.68	4.26	5.00	5.55	3.19	4.11	4.71	5.48	6.05	3.42	4.39	5.04	5.85	6.46	3.97	4.43	4.99	5.71	6.24
	c.l.	0.40	0.62	0.80	1.04	1.22	0.42	0.66	0.84	1.08	1.28	0.46	0.70	0.90	1.16	1.38	0.46	0.66	0.78	1.02	1.18
Kankesanthurai		2.47	3.49	4.17	5.02	5.66	3.04	4.16	4.91	5.85	6.55	3.66	4.81	5.57	6.54	7.25	4.29	5.90	6.97	8.31	9.32
	c.l.	0.46	0.72	0.92	1.18	1.38	0.52	0.78	1.00	1.30	1.54	0.52	0.80	1.02	1.32	1.56	0.72	1.12	1.44	1.86	2.18
Kurunegala		3.38	4.44	5.15	6.04	6.71	3.94	4.73	5.25	5.92	6.41	4.26	4.95	5.45	5.98	6.41	4.47	5.33	5.91	6.63	7.16
	c.l.	0.56	0.86	1.10	1.42	1.66	0.42	0.66	0.80	1.04	1.24	0.36	0.54	0.70	0.92	1.08	0.44	0.68	0.88	1.14	1.34
Mahailupallama		3.39	4.69	5.55	6.63	7.43	3.73	4.95	5.76	6.79	7.54	3.77	5.06	5.98	7.00	7.80	4.16	5.74	6.78	8.10	9.08
	c.l.	0.64	0.98	1.24	1.62	1.90	0.60	0.92	1.18	1.52	1.80	0.64	0.98	1.24	1.62	1.80	0.78	1.18	1.52	1.96	2.32
Mannar		2.36	3.03	3.48	4.05	4.47	2.74	3.64	4.23	4.97	5.39	3.12	4.17	4.87	5.75	6.41	3.86	5.48	6.55	7.90	8.90
	c.l.	0.36	0.56	0.72	0.92	1.08	0.48	0.74	0.94	1.22	1.44	0.56	0.86	1.12	1.44	1.70	0.86	1.30	1.70	2.20	2.60
Nuwara Eliya		1.82	2.31	2.63	3.04	3.34	2.37	2.99	3.40	3.91	4.29	2.97	3.82	4.37	5.08	5.62	3.43	4.59	5.35	6.32	7.04
	c.l.	0.20	0.32	0.40	0.52	0.62	0.26	0.40	0.52	0.66	0.78	0.36	0.54	0.70	0.92	1.08	0.50	0.76	0.96	1.26	1.46
Puttalam		2.57	3.28	3.74	4.33	4.77	2.92	3.69	4.20	4.85	5.33	3.09	3.91	4.45	5.13	5.64	3.49	4.40	5.01	5.77	6.34
	c.l.	0.34	0.52	0.68	0.88	1.04	0.38	0.58	0.74	0.96	1.14	0.40	0.62	0.78	1.02	1.20	0.44	0.68	0.88	1.14	1.34
Ratnapura		3.54	4.71	5.48	6.46	7.18	4.23	5.19	5.83	6.63	7.23	4.68	5.57	6.16	6.91	7.47	5.38	6.53	7.19	8.25	8.97
	c.l.	0.60	0.92	1.20	1.54	1.82	0.50	0.76	0.98	1.28	1.50	0.46	0.72	0.92	1.18	1.40	0.60	0.92	1.18	1.52	1.78
Trincomalee		3.17	4.29	5.03	5.97	6.66	3.87	5.27	6.19	7.36	8.22	4.46	5.96	6.96	8.22	9.15	5.23	6.79	7.82	9.12	10.09
	c.l.	0.54	0.82	1.04	1.36	1.60	0.66	1.02	1.30	1.70	2.00	0.72	1.10	1.42	1.82	2.14	0.74	1.14	1.46	1.90	2.22
Vavuniya		3.13	4.02	4.61	5.35	5.90	3.74	4.90	5.50	6.36	7.04	4.58	6.13	7.17	8.49	9.47	5.47	7.72	9.21	11.09	12.48
	c.l.	0.50	0.76	0.98	1.26	1.48	0.58	0.90	1.16	1.50	1.76	0.68	1.34	1.72	2.24	2.62	1.24	1.92	2.46	3.18	3.74
Watawala		2.75	3.90	4.67	5.63	6.35	4.20	5.83	6.90	8.25	9.26	5.74	7.88	9.29	11.07	12.39	7.88	10.78	12.69	15.11	16.91
	c.l.	0.48	0.76	0.96	1.24	1.46	0.68	1.06	1.36	1.76	2.06	0.90	1.38	1.78	2.30	2.70	1.22	1.84	2.42	3.14	3.68

Note: c.l. = 2 x standard error thus 95 per cent confidence limits = rainfall estimate ± c.l.

To obtain rainfall estimates in millimetres multiply by 25.4.

(*b*) Performing the χ^2 goodness-of-fit test using five class intervals;

(*c*) Computing rainfall estimates (for the different durations) with 2-, 5-, 10-, 25- and 50-year return periods;

(*d*) Obtaining the standard errors for these estimates.

In over 90 per cent of the cases, the derived EV1 distributions have been found to fit at a level of significance greater than 10 per cent, implying a satisfactory fit. A summary of the DDF relationships is given in table 7, while table 8 summarizes the derived estimates.

3. Regional analysis

Since the individual station records are relatively short (less than 25 years), the derived DDF relationships cannot be used for high return periods (e.g., greater than 50 years) with very much confidence (Bell 1969). This lack of confidence, together with the inadequate coverage of the island provided by the available stations, prompted a regional rainfall DDF study.

The individual station data sets were compounded to yield larger regional data samples. This approach has been successfully applied in rainfall studies by many researchers, including NERC. Nevertheless, cautious optimism has to be displayed in compounding data sets because of the folowing assumptions which are inherent in such a scheme: (*a*) that the annual maximum events are independent; and (*b*) that the compounded data sets will contain a selection of falls sufficiently varied to represent a long period.

In this study, neither of these assumptions can be guaranteed to be absolutely valid for any combination of stations, but the first should be reasonably accurate, owing to the spread of the stations and the localized convective nature of the rainfall. Since a variable rainfall pattern is distinguishable over the country, mainly because of the effects of the monsoon and the topography, the following climatic and topographical characteristics were considered in compounding the individual station data sets to form the regions:

(*a*) The 5-year return period rainfall for 3- and 24- hour durations (obtained from the study for individual stations);

(*b*) Altitude of the stations;

(*c*) The rainfall pattern of the stations characterized by:

(i) Mean annual rainfall;

(ii) Average rainfall during the south-west monsoon period, i.e., May-September;

(iii) Average rainfall during the north-east monsoon period, i.e., October-February.

Table 9 gives the suggested regional groupings, including the range of the above characteristics, and figure VII shows the location and extent of the regions. The criteria adopted to define the regions helped to achieve fairly clear regional boundaries, although a few more stations, particularly in regions V and VI, would have been useful.

Once the regions were defined, the respective individual station records were compounded as follows. The records from the rain-gauge stations in each region were taken together to give regional record totals in station-years. The regional data samples then became 61, 91, 73, 48, 41 and 17 years for the six regions, respectively. This amalgamation of annual maximum values assumes that they are independent and that the stations are representative of their regions defined from the criteria of table 9. These compounded records were then subjected to an analysis similar to that executed for the individual stations. This involved (for the different regions and durarions):

(*a*) Fitting an EV1 distribution to the longer annual maximum series using the maximum likelihood method;

(*b*) Performing the χ^2 goodness-of-fit test using ten class intervals (except for region VI where five class intervals were used);

(*c*) Computing rainfall estimates with 2-, 10-, 25-, 50-, 100- and 200-year return periods;

(*d*) Obtaining the standard errors for these estimates.

Here too, in over 90 per cent of the cases, the derived EV1 distributions were found to fit at a level of significance greater than 10 per cent, implying a satisfactory fit.

A summary of the regional DDF relationships is given in table 10, while table 11 summarizes the derived estimates. Figure VIII shows plots of the derived regional DDF relationships.

The regional rainfall estimates are compatible with the individual station estimates for return periods up to 50 years. The longer lengths of the regional data samples, except for region VI, allow more confidence to be attached to rainfall estimates for the higher return periods obtained from the regional DDF relationships.

Conclusions

The results of this study should satisfy a long-felt need for rainfall DDF relationships for Sri Lanka. Although the available station records are of relatively short lengths, the station-year concept adopted in the regional study helps to overcome this problem to some extent. The regional study also enabled rainfall DDF relationships to be developed for the whole country, thereby increasing the scope of the results.

The satisfactory goodness-of-fit results obtained justify the use of the EV1 distribution. This, together with the maximum likelihood fitting method used, should enhance confidence in the results. Nevertheless, the estimates for the higher return periods (i.e., greater than 100 years) should be used with caution since even the period lengths of the regional samples are less than 100 years. In this context the confidence limits of the estimates should be kept in mind during design.

Although the coverage of the country by the individual stations is rather sparse in certain areas, the variety of characteristics adopted for the regional classification helps to define the regions satisfactorily. The regions clearly reflect the effects of the monsoons and the topography of the island. Nevertheless, a few more rainfall stations, particularly in regions V and VI, will help to define the regions with more confidence in the future.

Finally, the regional results are recommended for design purposes. The use of these results rather than those for individual stations follows primarily from the larger regional samples which logically should provide more confident estimates, particularly for the higher return periods. The analyses described above should be repeated in perhaps 10 years time when, with longer autographic records and hopefully measurements from further stations, the regions might be more precisely defined and regional DDF relationships obtained within narrower confidence limits.

Acknowledgements

The authors wish to thank D.G.L. Ranatunga, formerly of the Irrigation Department, Sri Lanka and G.E.M. Gomes of the Irrigation Department, Sri Lanka for supplying the data utilized in this study. The encouragement given by Sir William Halcrow and Partners, Consulting Engineers, London is much appreciated. Most of this study was carried out during V.R. Baghirathan's post-graduate studies at Imperial College, London, where the computing was carried out on the College's CDC 6400 system.

Bibliography

Anonymous, 1972. Report on the Colombo Observatory for 1967. Colombo, Director, Department of Meteorology.

Bell, F.C., 1969. Generalized rainfall-duration-frequency relationships. American Society of Civil Engineers (ASCE), *Journal of the Hydraulics Division* 95 (HY1): 311-327.

Boucher, K., 1975. Global climate. London, English Universities Press.

Brooks, C.E.P. and Carruthers, N., 1946. The distribution of heavy rain in one and two hours. *Water Engineering, pp. 275-282.*

Clarke, R.T., 1973. Mathematical models in hydrology. Food and Agriculture Organization of the United Nations (FAO), Irrigation and Drainage Paper No. 19

Jenkinson, A.F., 1969. Estimation of maximum floods. World Meteorological Organization (WMO), Technical Note No. 98, chap. 5.

Natural Environmental Research Council (NERC), London, 1975. Flood studies report, vols. I and II (prepared by the Institute of Hydrology, Wallingford).

Table 9. Characteristics defining the regions

Region	Station	Height (above MSL) in metres	Five-year return period rainfall in millimetres		Mean annual rainfall in millimetres	Monsoonal rainfall in millimetres	
			3-h duration	24-h duration		South-west (May-Sept.)	North-west (Oct.-Feb.)
I	Amparai Batticaloa Trincomalee Vavuniya	6-98	102-109	173-196	1524-1905	203-381	889-1397
II	Anuradhapura Kankesanthurai Mannar Mahaillupullama Puttalam	3-134	76-119	112-150	1016-1524	127-229	635-965
III	Colombo Galle Kandy Kurunegala	6-509	89-114	112-185	2032-2540	762-1143	889-1143
IV	Hali-Ela Ratnapura Watawela	37-994	99-119	165-274	2540-5461	1016-2032	1016-1473
V	Badulla Nuwara Eliya	671-1900	58-71	109-117	1778-2159	457-1143	965-1397
VI	Hambantota	18	92	135	1016	279	635

Table 10. Rainfall depth-duration-frequency relationships for the regions

Region	3-hour	6-hour	12-hour	24-hour
Region I	$x = 2.764+0.907y$	$x = 3.289+1.108y$	$x = 3.885+1.353y$	$x = 4.594+1.764y$
Region II	$x = 2.436+0.874y$	$x = 2.841+0.939y$	$x = 3.030+0.952y$	$x = 3.479+1.215y$
Region III	$x = 2.817+0.845y$	$x = 3.368+0.947y$	$x = 3.771+1.039y$	$x = 4.078+1.198y$
Region IV	$x = 2.692+1.092y$	$x = 3.707+1.290y$	$x = 4.567+1.585y$	$x = 5.671+2.262y$
Region V	$x = 1.794+0.497y$	$x = 2.261+0.551y$	$x = 2.666+0.718y$	$x = 2.970+0.987y$
Region VI	$x = 2.448+0.789y$	$x = 2.995+0.809y$	$x = 3.177+0.824y$	$x = 3.521+1.158y$

Note: x = rainfall in inches; $x \times 25.4$ = rainfall in millimetres.

y = reduced variate = $-\ln[\ln(T/(T-1))]$

T = return period in years.

Table 11. Rainfall depth-duration estimates for the regions for selected return periods

Return period (years)		Region I				Region II				Region III			
		Duration (h)				Duration (h)				Duration (h)			
		3	6	12	24	3	6	12	24	3	6	12	24
2		3.10	3.69	4.38	5.24	2.76	3.18	3.43	3.92	3.13	3.72	4.15	4.52
	c.l.	0.28	0.34	0.41	0.53	0.22	0.24	0.24	0.30	0.24	0.26	0.28	0.32
5		4.12	4.95	5.91	7.24	3.75	4.25	4.51	5.30	4.08	4.79	5.33	5.88
	c.l.	0.42	0.52	0.62	0.82	0.32	0.36	0.36	0.46	0.36	0.40	0.44	0.50
10		4.81	5.78	6.93	8.56	4.40	4.95	5.22	6.21	4.72	5.50	6.11	6.77
	c.l.	0.54	0.66	0.80	1.04	0.42	0.46	0.46	0.58	0.46	0.52	0.56	0.64
25		5.67	6.83	8.21	10.24	5.23	5.84	6.13	7.37	5.52	6.40	7.10	7.91
	c.l.	0.70	0.86	1.04	1.36	0.54	0.58	0.60	0.76	0.60	0.66	0.74	0.84
50		6.30	7.61	9.16	11.48	5.85	6.51	6.80	8.22	6.11	7.06	7.83	8.75
	c.l.	0.82	1.00	1.22	1.59	0.64	0.70	0.70	0.90	0.70	0.78	0.86	0.98
100		6.94	8.39	10.11	12.71	6.46	7.16	7.46	9.07	6.70	7.72	8.55	9.59
	c.l.	0.94	1.14	1.40	1.83	0.74	0.80	0.80	1.02	0.80	0.90	0.98	1.14
200		7.57	9.16	11.05	13.94	7.06	7.81	8.12	9.91	7.29	8.38	9.28	10.42
	c.l.	1.06	1.30	1.59	2.07	0.84	0.90	0.90	1.16	0.90	1.02	1.12	1.28

		Region IV				Region V				Region VI			
		Duration (h)				Duration (h)				Duration (h)			
		3	6	12	24	3	6	12	24	3	6	12	24
2		3.09	4.18	5.15	6.50	1.98	2.46	2.93	3.33	2.73	3.29	3.48	3.95
	c.l.	0.38	0.44	0.54	0.76	0.18	0.20	0.26	0.36	0.46	0.46	0.44	0.66
5		4.33	5.64	6.95	9.06	2.54	3.09	3.74	4.45	3.63	4.21	4.41	5.26
	c.l.	0.56	0.68	0.82	1.18	0.28	0.32	0.40	0.56	0.71	0.70	0.72	1.02
10		5.15	6.61	8.13	10.76	2.91	3.50	4.28	5.19	4.22	4.82	5.03	6.13
	c.l.	0.74	0.86	1.06	1.52	0.36	0.40	0.52	0.78	0.91	0.90	0.92	1.30
25		6.19	7.83	9.64	12.91	3.38	4.02	4.96	6.13	4.97	5.58	5.81	7.23
	c.l.	0.94	1.1	1.38	1.96	0.46	0.52	0.68	0.98	1.08	1.18	1.20	1.66
50		6.95	8.74	10.75	14.50	3.73	4.41	5.47	6.82	5.53	6.15	6.39	8.04
	c.l.	1.12	1.32	1.62	2.30	0.54	0.60	0.80	1.08	1.39	1.38	1.40	1.98
100		7.72	9.64	11.86	16.08	4.08	4.80	5.97	7.51	6.08	6.72	6.97	8.85
	c.l.	1.28	1.50	1.86	2.64	0.62	0.70	0.90	1.24	1.60	1.58	1.62	2.28
200		8.48	10.54	12.96	17.65	4.43	5.18	6.47	8.20	6.63	7.28	7.54	9.65
	c.l.	1.34	1.70	2.10	3.00	0.72	0.78	1.02	1.42	1.80	1.80	1.84	2.58

Note: To obtain rainfall estimates in millimetres multiply by 25.4.
c.l. = 2 x standard error; thus 95 per cent confidence limits = rainfall estimate ± c.l.

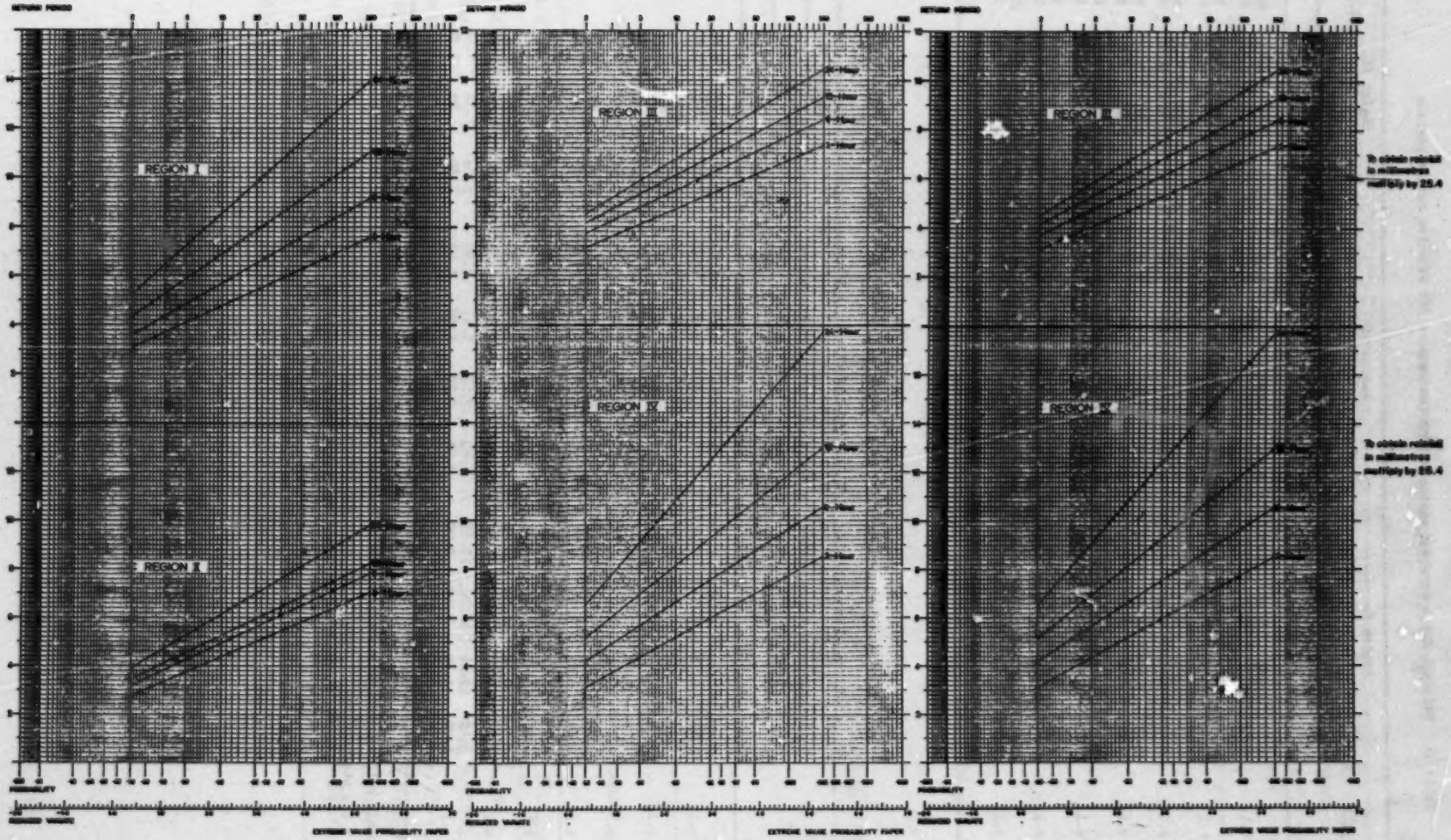


Figure VIII. Regional rainfall depth-duration-frequency relationships for regions I-VI in Sri Lanka

RESEARCH AND DEVELOPMENT

Chemical side effects of chlorine, chlorine dioxide and ozone[1]

The chemical side-effects of chlorine, ozone and other disinfectants used to treat drinking water "should be examined in more detail" before alternatives to chlorination are recommended, two National Research Council (NRC) subcommittees recently concluded. "Even in the case of chlorine, all . . . (chemical) side-effects are not fully understood", the subcommittees said. They advised EPA that sufficient research is lacking under actual water treatment conditions to provide an adequate understanding of the reaction of disinfectants and their by-products.

Alternatives to chlorination for disinfecting drinking water have been of interest since the discovery that chlorine forms potentially harmful trihalomethanes in water containing organics. Chlorine is widely used in the United States. Ozone, used widely for drinking water disinfection outside the United States, is as effective and apparently does not react with organics to form trihalomethanes. However, unlike chlorine, it fails to continue acting as a disinfectant after water leaves the treatment facility. Chlorine dioxide does not form trihalomethanes but may react to form other harmful by-products.

The subcommittee reports, two of seven being written by the NRC Committee on Safe Drinking Water, are part of a series of studies requested by EPA as follow-up to the NCR 1977 report on drinking water and health. The full report, which will also include upcoming studies on the mineral nutrition of drinking water and the absorption of impurities using granular activated carbon, was to be completed in late 1979.

Home drinking water treatment devices[2]

Analysis of the effectiveness of small faucet-mounted and portable pour-through and line by-pass home drinking water treatment devices found variable results in seven devices tested. An EPA study found that the small faucet-mounted and portable units were the least effective for removing organic chemicals from raw water. A stationary unit was rated "intermediate", and a line by-pass unit was found to remove the highest percentage of trihalomethanes. The analysis was designed to examine the effectiveness of removing trihalomethanes and total organic carbon. Another phase of the work examined bacterial growth on filter elements and resulting bacteria pass-through to the finished water.

Some of the home filtration units removed up to 93 per cent of the trihalomethanes from raw water but none removed more than 41 per cent of total organic carbon. Total organic halogen removals were found "variable". Two tests to determine trihalomethane removal efficiencies used water from a tap and water spiked with chloroform. Contact times ranged from 1 to 46 seconds.

Bacteria growth tests showed that some bacteria grow rapidly on the filtration elements where no active disinfectant is present; EPA found that these bacteria were not harmful to health and that the levels of the endotoxins measured were not known to cause adverse health effects. Prices of the units tested ranged from $US 10 to $US 400. A total of 30 home treatment units will be tested by EPA in its study.

Small hydro in China[3]

Of China's 2,000 counties, 1,500 have their own system of mini hydro plants. The small plants are mostly in the south of the country, and are particularly valuable in remote areas with only small water resources, where hydro development on a larger scale would not be economically or technically feasible, at least for the time being. Capacities from small stations for various provinces include: Guangdong, 750 MW; Guangxi, 550 MW; Sichuan, 550 MW; Hunan, 450 MW; and Fujian, 410 MW.

M. Djurović in his article, "Small hydro in China", describes the intensive building programme of small plants, which began in 1970. By the end of 1978, there were 84,500 mini schemes in the country, supplying about 10 per cent of the total installed capacity; the smallest of these was 5 kW, and the largest 12 MW. It is planned to produce 7,000 MW from this type of plant by 1987.

Details are given of some of the projects, for example, the First Branch Canal cascade in Linhsien county, Hunan province, where there are 22 mini hydro schemes, with a total capacity of 1.085 MW. A substantial section of the article describes developments

---

1 Reprinted from *Water Newsletter*, vol. 21, No. 12 (29 June 1979).

2 Reprinted from *Water Newsletter*, vol. 21, No. 12 (29 June 1979).

3 By M. Djurović, *Energy International*, November 1979, pp. 44-46. Abstract reprinted in *Water Power and Dam Construction*, vol. 32, No. 2 (February 1980), p. 60.

in Conghua county in Guangdong, where small hydro has been installed to exploit water already used for irrigation. County authorities operate 139 plants there and 80 per cent are connected to the county grid. The locations of the schemes in this area are shown.

The author concludes by underlining the suitability of small hydro for developing countries and notes that the construction of these plants should be encouraged throughout the world, in view of the increased costs of fossil fuels.

Researchers use iron to indicate ground-water component of streamflow[4]

The problem of separating total streamflow into its ground-water and direct runoff components has long interested hydrologists. Hydrographical analysis techniques have been proposed, but they are not altogether satisfactory. Now attention is focused on chemical techniques for estimating the ground-water component.

In their paper "Dissolved iron - an indicator of the groundwater component of small streams draining a granite terrain, South Carolina", published in *Water Resources Research* in February 1979, scientists I. Kheoruenromne and L.R. Gardner note that the simplest models result when the concentration of the chemical in the direct runoff is zero or negligible compared with its concentration in ground water. Often, total dissolved solids (TDS) is used, but in most cases, TDS in runoff is neither negligible nor constant. While studying two streams in the South Carolina Piedmont, the researchers noted that, unlike other chemical species, the seasonal export of total dissolved iron showed no dependence on stream discharge and was constant from season to season. This independence suggested that the total export of iron by stream water was controlled by the steady seepage of iron-rich ground water into the stream and that the dissolved iron content of the stream, therefore, is controlled by the simple dilution of iron-rich ground water by iron-free runoff. The researchers prepared a simple mixing model based on this hypothesis and it was found to fit the data.

Simple solar well pumps in prototype stage[5]

Howard P. Stubbs of the Solar Pump Corporation has developed an improved solar-powered well pump, which integrates a solar collector with components such as a Freon boiler, engine, controls and condenser into an 120 sq ft compact unit. This unit can deliver 4,000 gallons per day against a 40-foot head if operated at 38^{0} north or south latitude. The pump automatically begins to work three hours after sunrise and continues at a deliberate pace until three hours before sunset; on partly cloudly days, it stops and starts. Currently, prototype units are being tested in India and England by World Bank consultants.

Water is more complicated than was once believed[6]

For many generations, science students have laboured under the false assumption that water is H_2O, meaning that every molecule of water ionizes into two components, one of which is a positively charged hydrogen (H+) ion and the other a negatively charged hydroxyl (OH-) ion.

In recent years, however, the water molecule and its ions have turned out to be far more complicated than was once believed. Now, George Mateeson and George Benedikt, chemists at Case Western Reserve University, have demonstrated the existence of a long-suspected component of water, the hydronium ion: H_3O+. In a related report in the *Journal of the American Chemical Society*, another research team, Kenneth Raymond, Dereck Freyberg and Kamul Abu-Dari of the University of California, reported the discovery of another water component, the bihydroxide ion: $H_3O_2^-$.

The means used to gather information about these ions were among the most sophisticated in science and involved X-ray diffraction, nuclear magnetic resonance and mass spectrometry, among other techniques. The apparent simplicity of water has become increasingly clouded, and investigation of the energy and geometry of the electrons that bind together the constituent atoms has proved extremely complicated.

Since water and its ions interact with most other substances, including the building blocks of all living things, discoveries about the fundamental structure of water are expected to have far-reaching scientific consequences.

Assistance by United States agencies to develop China's hydro resources[7]

United States Vice-president Walter Mondale signed an agreement at Peking in late 1979 which provided for technical assistance to be given by the Corps of Engineers, the Tennessee Valley Authority, the Bureau of Reclamation and the Bonneville Power Authority to help China to exploit its vast hydropower resources. China has an estimated hydroelectric potential of 580,000 MW and only about 2.5 per cent of this has been developed.

The largest project under consideration is still pending. The Three Gorges, about 95 miles upstream from Yichang, with its generating capacity of 25,000

---

4 Reprinted from *The Ground Water Newsletter*, vol. 8, No. 9 (15 May 1979).

5 Reprinted from *Solar Energy Digest*, November 1979. Reprinted in *The Ground Water Newsletter*, vol. 8, No. 22 (30 November 1979).

6 From *The New York Times*, 27 November 1979. Reprinted in *The Ground Water Newsletter*, vol. 8, No. 23 (17 December 1979).

7 Reprinted from *International Water Report*, Autumn 1979.

to 30,000 MW, would be four or five times larger than any power complex on earth. The ambitious programme would flood more than 120,000 ha of scarce farmland, displace more than a million people and temporarily disrupt river traffic. On the drawing board for 30 years, the Three Gorges project has an estimated cost of $US6.2 billion.

Other projects, which are expected to be implemented much sooner, include a 2,700 MW regulating dam for the Yangzi gorge project, and the Longtai Dam on the Hongshui, which will be 200 m high with a 3,000 MW capacity. This project is near newly discovered bauxite deposits. The Jinbing Dam on the Yalong River will have an eventual capacity of 6,000 MW. A 16-km pressure tunnel linking two sections of the river would be required, providing a head of 300 m at the outlet. A dam downstream would be built in the second stage. The Longmen Dam on the Yellow River would have an installed capacity of 1,500 MW and would provide flood control, irrigation and sedimentation control. Xialondi would have a capacity of 1,600 MW and would require a very large reservoir because of heavy sedimentation of the Yellow River. Xiangjiaba, on the Yangzi, would have a capacity of 5,000-6,000 MW.

Included in the agreement were assurances that financing of over $2 billion would be available to China during the next five years through the United States Export-Import Bank.

CONFERENCE, SYMPOSIA, TRAINING COURSES

Water Reuse Symposium II

The American Water Works Association Research Foundation is organizing Water Reuse Symposium II under the sponsorship of the Office of Water Research and Technology (United States Department of the Interior), the Department of Defense, the National Science Foundation, the Environmental Protection Agency and the Water Pollution Control Federation. This second week-long series of meetings devoted entirely to renovation and reuse of waste waters from municipal, industrial and agricultural sources will be held in Washington, DC from 23 to 28 August 1981. Under the theme "Water reuse in the future", subjects to be covered include recent case histories, new water recycling research and practical applications. In the selection of papers, special consideration will be given to innovative approaches, such as: (*a*) new, updated or unreported system design and performance data; and (*b*) practical applications of water reuse as a method of satisfying pollution discharge requirements, as a conservation technique or as an economical and energy efficient water supply alernative. Special emphasis will also be given to the recycling of water by industry, municipalities and agriculture.

The programme is directed towards: (*a*) individuals from water and waste-water utilities; (*b*) consulting firms; (*c*) Federal and State research/regulatory agencies; (*d*) divisions of manufacturers and departments responsible for water supply, reuse and recycling; (*e*) universities; and (*f*) other water organizations. The goal of the Symposium is to transfer the latest technology between users and from researchers to users by means of formal papers given at technical sessions or poster presentations designed for one-to-one communication.

In addition to an abstract information sheet, interested parties should submit 10 copies of an abstract no more than two pages long by 15 December 1980. The abstract information sheet can be obtained from:

Richard D. Heaton
Water Reuse Symposium II
AWWA Research Foundation
6666 West Quincy Avenue
Denver, Colorado 80235
United States
Phone: 303-794-7711.

Completed abstracts and information sheets should be sent to the above address.

International Symposium on Water Resources Systems, 20-22 December 1980, Roorkee, Uttar Pradesh, India

1. Objective

The purpose of the programme is to provide a forum for communicating recent advances in the field of water resources systems and to focus attention of field and practising engineers towards the potential application of systems analysis in the solution of practical problems. The state-of-the-art will be reviewed and knowledge and experience gained in this field will be pooled to achieve economy, reliability and safety in planning, construction and management of water resources projects. An opportunity for field engineers, consultants and academicians will be provided to present their ideas and exchange experience.

2. Venue and date

The Symposium will be held at the University of Roorkee from 20 to 22 December 1980; it will be concurrent with the 1980 Silver Jubilee celebrations of the Water Resources Development Training Centre, which was founded 25 years ago.

3 Themes

The following themes have been selected for the Symposium:

(*a*) Planning of water resources schemes

- (i) Plan formulation for hydropower, flood control, irrigation and other uses;
- (ii) Economic evaluation;
- (iii) Techniques of systems analysis;
- (iv) Hydrologic analysis and water resources evaluation;

(*b*) Construction of water resources schemes

- (i) Planning for construction;
- (ii) Construction management and control;
- (iii) Simulation in construction;
- (iv) Ecological aspects in construction;

(*c*) Reservoir operation

- (i) Single and multiple reservoir systems;

(ii) Operation for hydropower, flood control and irrigation;

(iii) Control of water quality;

(*d*) Water use and management

(i) Farm application;

(ii) Land and water management;

(iii) Conjunctive use of surface water and ground water;

(iv) Ground-water systems;

(*e*) Hydropower systems

(i) Conventional hydropower systems;

(ii) Pumped storage hydropower systems;

(iii) Alternate hydropower systems: low head, small scale, hybrid combinations of hydroelectric facilities with wind or solar energy plants;

(iv) Transmission systems.

4. Field trips and tours

A one-day field trip will be planned just after the Symposium to important nearby water resources projects. These include the Ganga Canal Works and the Yamuna Hydroelectric Project. The Ganga Canal, constructed over 130 years ago, is the oldest irrigation works in this region of the world.

Holiday tours to Himalayan resorts can also be arranged.

5. Registration

The registration fee for each delegate is Rs 300 ($US 50). Spouses are welcome and there is no fee for them. Additional information can be obtained from:

Organizing Secretary
International Symposium on Water Resources Systems
Water Resources Development Training Centre
University of Roorkee
Roorkee, Uttar Pradesh 247 672
India.

SELECTIVE INFORMATION SECTION*

* Most of the abstracts reproduced below are from the Selected Water Resources Abstracts of the Water Resources Scientific Information Center, Office of Water Research and Technology, United States Department of the Interior, for which acknowledgement is hereby gratefully recorded.

Subject	Source	Description
Conservation in agriculture	A. Fochessati, "Orchard irrigation scheduling: results of a preliminary investigation", *The Deciduous Fruit Grower*, vol. 28, part 8 (August 1978), pp. 290-299	To estimate the rate and frequency of irrigation for any application during the growing season, the influence of the following factors must be assessed with regard to the time of the season: (*a*) climate, including temperature, wind, and humidity; (*b*) type of ground cover in the orchard; (*c*) total leaf area of both the trees and the cover crop; (*d*) water retention capacity of the soil in the root zone; (*e*) irrigation method and the relative efficiency of water utilization; and (*f*) orchard aspect. An investigation being conducted in an apple orchard is described in which evaporation data obtained from an evaporimeter is used. In assessing the values of a rainfall and an equivalent volume of water applied by microjets, the quantity of water consumed by the trees at various stages during the season must be considered. The difference between consumptive requirements of the tree and actual water consumed to satisfy this requirement can be attributed to the method of application. In orchards where strip irrigation is employed, the area watered is restricted to less than half the total ground surface. Where irrigation application is over the entire surface, evapotranspiratory losses are increased by the water consumption of the sod grown in the alley-ways and evaporation from the larger surface area, which includes the sod leaf surface area and the soil immediately below the surface. When a pattern of irrigation requirement has been developed and the "crop factor" worked out, evaporation records can be used to determine irrigation scheduling according to seasonal needs.
Conservation in domestic and municipal use	D.E. Warner, "Water conservation: residential impacts". Available from the National Technical Information Service, Springfield, Virginia 22161, as No. AD-A053 522 (June 1977)	The purpose of this study is to determine the constraints and misunderstandings associated with residential water conservation and to analyse the actual savings in dollars, water and energy that are achieved by the selection and installation of water-conserving facilities. Six areas having potentially valuable input to development of a residential water conservation programme are: (*a*) cultural attitudes; (*b*) institutional impacts; (*c*) economic aspects; (*d*) technological alternatives; (*e*) public education; and (*f*) residential water usage patterns. These areas are analysed with regard to their relationship to water-saving measures, myths concerning water supply, pricing measures and water conservation, water demand and other aspects of water conservation. The author investigates the selection and application of water-conserving facilities in residential homes at Mesa, Arizona, located in the eastern portion of Maricopa County, 16 miles east of Phoenix. The analysis begins with a brief summary on the growth of Mesa and a discussion of current household water usage and fixture consumption. A review of the water-saving devices and appliances to reduce consumption is presented. An acceptable list of water-using devices and appliances is developed for consideration in both existing and new homes and each is evaluated for residential unit water savings and costs. Conclusions indicate that

Subject	*Source*	*Description*
		residential water conservation would relieve volume loading on sewage facilities and reduce energy demand. Total water savings and costs were also formulated. An appendix lists reasons for reducing water consumption and another presents a summary of water conserving facilities.
Control of water on the surface	H.M.A. Kempen and H. Ton, "The effects of an urban area on the water management of a rural area", in *Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality*, Proceedings of the Amsterdam Symposium, October 1977	The discharge in a rural drainage system resulting from rainfall in built-up areas has been simulated by models of non-stationary flow. The results show that when floods are likely to occur in an existing system, the widening of the drainage channel along a few hundred metres is all that is required. This solution is much less drastic and cheaper than the construction of storage ponds. The foundations of many buildings are on wooden piles and it is essential that these piles stay below ground-water level. In projects for rural development, the water table is often lowered, putting the foundations of existing buildings at risk. It is possible to remedy this by local injections of water to maintain the water level at the foundations. If the buildings are sufficiently far from the drainage channels, additional measures are not necessary.
Cost allocation, pricing repayment	C.T. Haan, D.I. Carey and O.C. Grunewald, "Water conservation via a variable pricing mechanism", in *Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality*, Proceedings of the Amsterdam Symposium, October 1977	Increasing demands for water for urbanizing areas has demonstrated that it is no longer possible to meet "all foreseeable demands" for water. Curtailment of water usage can be implemented through the pricing structure of the water to consumers. An increase in water rates has been shown to reduce the consumption of water. By using a variable pricing strategy, it is possible to meet the demands for water when water is plentiful and yet to conserve water in times of shortage. The strategy consists of making water rates a function of available water so that the rates are low when water is in good supply and rates are increased when the supply is low. A policy of this nature has been shown to reduce greatly the capacity of a water supply system needed to meet the demands placed on it without greatly decreasing the amount of water supplied or increasing the average price of water. Various pricing policy alternatives are evaluated, using a stochastic simulation analysis and a water price-demand relationship derived from more than 150 water districts in the State of Kentucky.
Cost allocation, pricing/repayment	"Proceedings, North Carolina workshop on water and wastewater pricing", 21 February 1978, Raleigh, North Carolina State University at Raleigh, Water Resources Research Institute	Prices for water and waste-water services vary considerably between communities because each system is unique. Some factors which cause prices to vary include location of the supply, topography or terrain, age of the system, population density, type of consumer, area being served, growth, water quality and quantity, inflation and energy costs, fire facilities, general tax and level of treatment. The pricing of water and waste-water services is going up and utility managers need to be in a better position to explain new rate structures. New issues force us to review traditional approaches to rate setting. These issues include inflation,

Subject	Source	Description
		growth management, government regulations, especially those associated with the Clean Water Act and the Safe Drinking Water Act, energy costs, chemical costs and the need for conservation. This workshop raised issues related to establishing equitable rate structures which reflect the costs and services being provided and anticipated future needs. The general objective of the workshop was to provide a forum for leaders to discuss these issues and to hear experts discuss national pricing trends. The specific objectives were to present information on advanced approaches to rate setting, to demonstrate the relationship between water and waste-water pricing, to discuss unique problems of pricing in North Carolina, to present practical methods for solving pricing problems, to determine needs for training, research and further workshops and to present the opportunity to use water conservation as a management tool to reduce costs.
Effects of pollution	M.H. Al-Muhandis, "Pollution of river water in Iraq", in *Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality*, Proceedings of the Amsterdam Symposium, October 1977	One of the major problems resulting from undertaking an intensive housing programme and establishing farm drainage schemes in Iraq is water pollution of the two main rivers, the Tigris and the Euphrates. The pollution has taken place for the following reasons: (*a*) There are a large number of pumping stations along the Tigris near Baghdad discharging drainage water from the agricultural areas directly into the river; (*b*) There are a number of sewage pipes connected to the storm drainage network discharging directly into the main river; (*c*) There are some natural, old drains crossing heavily populated areas, carrying all kinds of effluent directly into the main rivers; (*d*) There are a number of private agencies for the removal of sewage from houses by tankers and these unload into the main river. Important points are given for consideration in the preparation of a plan for a sewerage network system.
Effects of pollution	A.J. de Groot and W. Salomons, "Influence of civil engineering projects on water quality in deltaic regions", in *Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality*, Proceedings of the Amsterdam Symposium, October 1977	The Dutch coastal region contains the mouths of a number of rivers (Rhine, Meuse, Scheldt) which are polluted to a considerable degree with heavy metals. The pollutants are largely associated with the suspended matter in the water. In the estuaries and lagoons, these solids were formerly diluted with relatively uncontaminated marine material and subsequently mainly transported out to sea. Meanwhile, civil engineering projects have resulted in the enclosure of the river mouths (Delta plan) and a lagoon (former Zuyder Sea), as well as in the construction of large harbours (Rotterdam). The creation of fresh-water lakes and deep harbours favours the sedimentation of polluted material and restricts discharge out to sea. Furthermore, the longer residence times of the river water in these reservoirs give rise to an increase in pH and an enhanced adsorption of dis-

Subject	*Source*	*Description*
		solved pollutant to the sediments. The above-mentioned processes were studied for many years in the relevant areas. The consequences of the enhanced retention of polluted sediments will be discussed with respect to environmental quality.
Effects of pollution	B.S. Mathur, "The pollution of water resources due to rural industrial waste", in *Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality*, Proceedings of the Amsterdam Symposium, October 1977	The pollution of surface and ground water owing to rapid industrialization in the central and western parts of the State of Uttar Pradesh in India is a growing problem. The urban industrial waste is treated partially or fully, but rural industries allow the spread of effluents in and around their premises. The problem is most acute in the case of the sugar industry, which is concentrated in the rural areas. A brief description is given of the nature of the industrial development and its effluent. The effect of effluents of the sugar indurtry on the unsaturated zone of soil is investigated. The mechanics of the pollution of the subsoil water is examined.
Effects on water of man's non-water activities	H. Bouwer, "Urbanizing irrigated valleys for optimum water use", *Journal of the Urban Planning and Development Division*, Proceedings of the American Society of Civil Engineers, vol. 105, No. UP1 (January 1979), pp. 41-49	Irrigated valleys of the south-western United States and other arid lands are prime areas for urbanization through expansion of existing towns in these valleys, since it is easier to build on flat land where water and roads are already available. Irrigated valleys frequently have limited water supplies, with most of the available water being used for irrigation. Urbanization in the valleys results in loss of irrigated land, increased flooding and reduced opportunities for reuse of sewage effluent. These disadvantages could be avoided if urbanization were to take place on the non-irrigated higher lands (deserts, foot-hills, etc.). Storm runoff from these lands would be spread over the lower agricultural land for irrigation and ground-water recharge. To ensure permanent irrigation, ground-water management of an irrigated valley must achieve a salt balance for the entire valley. Where ground-water levels are low, they can be brought up by a reduction in irrigation or by additional ground-water recharge. Once ground-water levels are sufficiently high, a programme of balanced withdrawal and replenishment of ground-water can be instituted to avoid long-term ground-water declines.
Effects on water of man's non-water activities	A. Kabbaj, I. Zeryouhi and Th. Pointet, "The water supply of Marrakesh: short, medium and long term schemes: influences on the water table" (in French), in *Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality*, Proceedings of the Amsterdam Symposium, October 1977	Tourist developments in the city of Marrakesh, Morocco, are causing an over-all growth and a particularly rapid increase in the needs for water. The forecast of these needs and their solutions will be integrated from 1981 onwards in a group scheme for the exploitation of the Haouz plain. This scheme foresees the optimal utilization of the surface and ground-water resources of the basins. It will utilize an important water supply that will be diverted from the neighbouring basin of Tassaout. A temporary over-exploitation of the water table will be called for and the effects of this have been researched. From 1981, the re-establishment of the piezometric level will be ensured by the infiltration of excess water from irrigation.

Subject	Source	Description
Estuaries	A.E.F. Heydorn, N.D. Bang, A.F. Pearce, B.W. Flemming and R.A. Carter, "Ecology of the Agulhas Current region: an assessment of biological responses to environmental parameters in the south-west Indian Ocean", *Transactions of the Royal Society of South Africa*, vol. 43, part 2 (May 1978), pp. 151-190	Multidisciplinary oceanographic research was carried out in the waters of the east coast of South Africa with emphasis on Natal. Natal coastal waters are characterized by the Agulhas Current, a very narrow continental shelf, the entry of many rivers into the sea, a series of large-scale surface water circulation patterns and a large number of estuarine systems. The distribution and transport of sediments, basic to the occurrence of benthic fauna and ecological patterns, is closely related to the interrelationship between bottom topography and circulation patterns. Temperature-induced responses, utilization of current transport and larval retention mechanisms and marine/estuarine interaction are given for calanoid *Copepoda*, *Chaetognatha*, spiny lobsters, marine turtles, sharks, estuarine fishes and teleost fishes. The responses and adaptations of the animals studied provide insight into the ecological mechanisms operating in this region. It is concluded that the high flow velocities of the Agulhas Current are responsible for the massive sediment transport and distribution among the Natal coastal waters.
Estuaries	M.A. Tayfun, "Joint occurrences in coastal flooding", *Journal of the Waterway, Port, Coastal and Ocean Division*, American Society of Civil Engineers, vol. 105, No. WW2 (May 1979), pp. 107-123	Extreme levels of coastal flooding arising from the joint occurrence of a rare event, such as a hurricane or a tsunami, with the astronomical tide have a stochastic nature resulting from the random occurrence of the primary event relative to the phase of the astronomical tide. Numerical means of computing the frequencies of peak flood levels by constructing equally likely combinations of tides with the record of a rare event are costly and impractical to apply. This paper presents an approximate analytic approach to construct the probability structure of extremal crest heights arising from such joint occurrences based on simple astronomical tide models. Examples are given to illustrate application to tsunamis and storm surges.
Evaluation process	"Cost effectiveness studies of sanitary sewerage systems: methodology and demonstration". Available from the National Technical Information Service, Springfield, Virginia 22161, as No. PB-253 372 (1974)	Methodologies and demonstrations of three cost-effectiveness studies of sanitary sewerage systems are presented. The first study is a cost comparison associated with eliminating extraneous flow problems in existing sanitary sewer systems. Six alternative solutions are demonstrated and the estimated project cost and present worth of each alternative system are calculated. The second study presents a cost comparison associated with selecting interceptor sewer routes. Two alternative plans are compared for estimated project costs and present worth. The third study compares the costs associated with waste-water treatment for outlying communities in metropolitan areas. Four alternative plans are developed and compared for estimated projects costs and present worth.
Evaluation process	P. Reavell, "The Okavango Delta: planning for the future", *South African Journal of Science*, vol. 74, No. 5 (May 1978), pp. 165-167	A symposium from 30 August to 2 September 1976 on the future management of the Okavango Delta at Gaborone, Botswana is reviewed. The topics covered include wildlife, tourism, game and trophy hunting, the possibility of combining cattle farming with game

Subject	Source	Description
		ranging, cattle husbandry, the eradication of such diseases as nagana and foot-and-mouth, aquatic resources, a fishing industry, water for industry, possible engineering changes to the hydrological regime, and exporting water to bordering countries. Specific changes likely to occur in the delta regardless of man's intervention are examined.
Evaluation process	P.R. Vance and L.C. Bryan, "Hydro power: economic comparisons". Available from the National Technical Information Service, Springfield, Virginia 22161 as No. PB-280 694 (30 December 1976)	Production cost equations for hydrogeneration and for fossil-fired alternatives are developed. The inflation of fuel, capital and labour costs was taken into account in determining the generation cost of power produced by these types of plants. A cost comparison is made of the 15-year period prior to the oil embargo of October 1973 and the first 15 years of operation of the plants currently in planning. The results show that the economic competitive position of hydroelectric generation has greatly improved because of the escalation of fuel costs. It is concluded that many potential hydroprojects, formerly uneconomic, may now be considered economically sound.
Ground water	S. Bagchi and A.S. Goodman, "Emergency water supplies from ground water in humid regions", *Water Resources Bulletin*, vol. 15, No. 2 (April 1979), pp. 536-549	This paper focuses on the development and testing of a mathematical model of an emergency ground-water supply operated principally during periods of low streamflow. The process of ground-water withdrawal and recharge was simulated, taking account of streamflow, water demand, evapotranspiraction, natural and artificial recharge and increased evapotranspiration due to artificial recharge, ground-water pumpage and streamflow contribution to pumped water. The model determined whether natural recharge is possible in less time than the return period of drought and also whether artificial recharge is needed. By simulating operation over a long period of time, the model can examine different droughts of short and long duration and can test the operating rules for ground-water storage development in an area. Submodels analyse the components of the operating process, including ground-water flow into the stream, seepage losses, stream portion of well discharge due to induced infiltration and recharge from rainfall or water spreading. The model has been tested for areas in the humid north-eastern United States.
Ground water	C.P. Gupta, M. Thangarajan and V.V.S. Gurunadha Rao, "Electric analog model study of aquifer in Krishni-Hindon interstream region, Uttar Pradesh, India", *Ground Water*, vol. 17, No. 3 (May-June 1979), pp. 284-290	Over-exploitation of ground water in the Krishni-Hindon interstream region (29°05'N-29°29'N and 77°19'E-77°32'E) in Uttar Pradesh, India, prompted the authors to carry out aquifer modelling studies. The area lies in the Gangetic alluvial plain. The interconnexion in the phreatic aquifer and the lower semi-confined aquifer led to the assumption of a single-storey aquifer for which an R-C analog model was constructed. The input-output quantities in the model were simulated using current/voltage generators and current sinks which were programmed appropriately in time-domain with the help of wave-form synthesizers for a realistic

Subject	Source	Description
		representation of the field system. The model study showed that the aquifer can sustain the present output rate of 200 million m^3 (mcm) per year without much damage to the ground-water regime. In another scheme, an annual increase of 5 per cent in exploitation rate showed deleterious effects on the aquifer. Decreased rainfall or droughts would worsen the situation. The influence of hydraulic connectivity between the aquifer and the Krishni-Hindon river system is quite significant. At present exploitation rates, it is estimated that in 20 years the annual inflow to the aquifer from rivers will have increased by about 36 mcm. More hydrogeological data are required for further validation and refinement of the model.
Ground water	L. Monition, "Effets de l'urbanisation sur les eaux souterraines" (Effects of urbanization on ground water), in *Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality*, Proceedings of the Amsterdam Symposium, October 1977	In France, the new law promulated in June 1976 concerning the protection of the natural environment states that the ground water and the subsoil are resources that must be protected from all forms of degradation. The effects of urbanization on ground water are characterized by changes in recharge, runoff, piezometric level, flow and physical and chemical properties. The quantitative evaluation of these impacts has now been made possible by means of simulation techniques which allow one to analyse and predict the detrimental changes. Some examples of the effects of urbanization on ground water (aquifers) are mentioned: galleries, tunnels, metros, underground parking, canalization of water courses, water supply and gravel pits.
Ground water	P.J. Smit, "Ground-water recharge in the dolomite of the Ghaap Plateau near Kuruman in the northern cape, Republic of South Africa", *Water S.A.*, vol. 4, No. 2 (April 1978), pp. 81-92	The flows of several natural springs on the dolomite of the Ghaap Plateau formation were measured between 1959 and 1970 to determine natural ground-water recharge. The underground catchment, or ground-water compartment, delineated from a survey of the water levels, has a surface area of about 1,140 sq km; ground water from this area is drained by four springs. In some of the 50 smaller subcompartments, springs drain the underground water into the adjoining compartment. A ground-water balance sheet was drawn up with all possible ground-water losses taken into account prior to measuring the flow at the point of discharge at the springs. Although the general ground water in the area is rarely less than 20 m below the surface, it ranged between ground level and 200 m below the surface. The average annual recharge during the study period was calculated to be 2.5 per cent of the 346 mm annual rainfall. Ground-water recharge, based on the potential evapotranspiration rate and calculated according to the Thornthwaite method, was 2.94 per cent for the 1940 to 1970 period, with an average rainfall of 445 mm.
Ground water	D. Wachs, A. Arad and A. Olshina, "Locating ground water in the Santa Catherina area using geophysical methods", *Ground Water*, vol. 17, No. 3 (May-June 1979), pp. 258-263	An attempt was made to locate ground water in an arid, mountainous area in the Santa Catherina region of the southern Sinai desert. A combination of classical geological methods, together with geophysical techniques, was found to be particularly useful for the locality studied. It was found that water flow was

Subject	Source	Description
		mainly through the joints of the crystalline basement and that, under favourable circumstances, fair groundwater supplies coned be found in alluvial valley fill. It was concluded that recharge of valley fill is derived mainly from the joint system of the bedrock and only partially from flooding.
Ground water	W.C. Walton, "Review of leaky artesian aquifer test evaluation methods", *Ground Water*, vol. 17, No. 3 (May-June 1979), pp. 270-283	Flow to wells in leaky artesian aquifers is intimately related to changes in aquitard storage, well storage capacity and degree of well penetration. The manner and extent to which these and other factors affect water levels may be evaluated with aquifer test data. Families of type curves describe time-drawdown in the aquifer and aquitard under complex aquifer and well-penetration conditions. Analysis of leaky artesian aquifer test data is possible with the array of equations derived largely from the 1950s through the 1970s. Erroneous data analysis will result unless complicating factors are fully recognized and taken into account. A review of leaky artesian aquifer test evaluation methods is presented in this paper, together with the field application of selected methods to foster greater use of current theories.
Hydraulic machinery	"Preventative maintenance: your most important investment", *Water Well Journal*, vol. 33, No. 6 (June 1979), pp. 51-54	Factors to consider in selecting a suitable drilling rig are capacity, average hole size, operating location, amount of use and the type of maintenance required. Preventive maintenance of the drilling rig is essential for warranty protection and getting the most out of the rig. If properly selected and used, a regularly serviced drilling rig can operate for more than 8,000 hours without requiring an overhaul or major repairs. Basic maintenance procedures for drilling rigs are outlined. Service steps for various parts are given in daily, weekly, bi-weekly, monthly, bi-monthly, quarterly, and semi-annual intervals. Proper lubrication is the key to good maintenance for any part. Thinner oils are required for very cold climates while, in hot weather, heavier oils are recommended. For altitudes greater than 8,000 feet a turbocharger should be added to the engine. Recommended safety precautions are listed which will prevent damage to the machine and ensure the safety of the crew.
Hydraulic machinery	E.M. Thain and P.H.H. Trendler, "A borehole probe for sampling ground-water from selected strata", *Water S.A.*, vol. 4, No. 2 (April 1978), pp. 49-53	A borehole sampling device capable of collecting groundwater samples up to a maximum depth of 200 m is described. Portions of the borehole are selected off by the device, allowing the water between the seals to be pumped to the surface for age determination, or to be collected in canisters for trace metal and chemical analysis. This device contains a submersible pump and consists of a probe, sample holder canisters, a water sensing mechanism, a specially designed lowering device with electrical winch, clamps, a drum for the electric cables and plastic tubes. The device operated successfully during testing of the probe and lowering mechanism. Preliminary tests indicate that the probe will be

Subject	Source	Description
		able to pump water to the surface from specific strata for age determination sampling. A schematic diagram of the probe is provided.
Identification of pollutants	W.G. Characklis, P.B. Bedient, F.G. Gaudet and F.L. Roe, "A study of storm-water runoff quality", *Progress in Water Technology*, vol. 10, No. 6 (1978), pp. 673-699	The storm water from four watersheds in the Houston area was monitored by an intensive sampling and analytical programme over a three-year period. The land use in the watersheds included undeveloped forest, developing forest, fully developed residential and mixed commercial-residential. Chemical parameters monitored included suspended solids, oxygen demand, organic carbon, nitrogen, phosphorous, dissolved oxygen, pH, specific conductance and chlorinated hydrocarbons. Indicator and pathogenic bacterial content were enumerated as well as aquatic and edaphic algae species. Disinfectant demand and algal bioassays were also conducted. Relationships were developed between storm-water runoff quality, quantity and land use in an effort to predict pollutant loads. The appearance of a "first flush" was dependent on the parameter measured and the watershed characteristics. Rain-water quality contributes significantly to storm-water pollutant load, especially in urbanized areas. The modifying effect of natural biological processes on nitrogen content in the runoff and the effects of the hydrological regime on nutrient limitations were observed. The effectiveness of storage lakes, very positive in the case of suspended solids, was described.
Non-structural alternatives	S.K. Paulson and W.E. Lawrence, "Survey and Evaluation of social science research on flood-damage abatement". Available from the National Technical Information Service, Springfield, Virginia 22161, No. PB-296 638 (June 1979), p. 99	Scientists, particularly engineers, biologists, geologists and economists, continue to research ways of preventing damage to life and property from the flooding of lakes, rivers and streams. As a result of such efforts, a variety of effective structural and non-structural flood-damage reduction methods have been developed. The human social aspects of such methods, however, have not been researched as extensively. This study documented the nature and extent of existing social science literature in this area and identified future research needs through six data collection efforts. Two types of information were compiled: social science research conducted to date and knowledgeable persons' perceptions of needed research. A bibliography of the most relevant extant materials was constructed and the contents of each entry were analysed. Results of this study indicate that most research on flood-damage reduction has focused on the economic and engineering aspects of the structural methods of damming and channelling and has been of the sponsored, case-study type of design. The sociological aspects of non-structural methods have received minor emphasis. Recommendations advocate additional research in the area of non-structural flood-damage reduction methods, focusing on such variables as the social attitudes, beliefs and behaviour of individuals and the social and political structure of communities.

Subject	*Source*	*Description*
Saline water conversion	W.A. Fernelius and M.K. Fulcher, "East Mesa geothermal test site", *Journal of the Environmental Engineering Division*, Proceedings of the American Society of Civil Engineers, vol. 105, No. EEI (February 1979), pp. 13-32	The results of a geothermal desalination programme at East Mesa, Imperial Valley, California, are described. The primary objective of this programme is to provide the necessary information to permit design, construction, operation and maintenance of economical and efficient desalting systems using geothermal fluids. Three types of geothermal units were tested: (*a*) a multistage flash (MSF) unit; (*b*) a vertical tube evaporator unit; and (*c*) a high-temperature electrodialysis unit. Studies on corrosion, scale prevention, water quality, materials and heat transfer were run concurrently with each test. All three desalting systems proved capable of desalting geothermal fluid. Problems associated with each are discussed along with possible solutions. Determination of the economic feasibility of geothermal desalting depends on other important factors, such as productivity of the geothermal reservoir, compatibility of fluids, environmental concerns and the source of replacement fluids. Data on these items are forthcoming and will provide the basis for the design and cost estimates for a production-size desalting plant. This study will include the feasibility of producing power concurrently with desalting.
Saline water conversion	A. La Rocca, "Desalination of salt water by solar energy means", United States Patent No. 4,135,985, *Official Gazette of the United States Patent Office*, vol. 978, No. 4 (23 January 1979), p. 1377	A desalination system is provided which has no moving parts, in which the heat given up on condensation of the water vapour is used for pre-heating the incoming salt water, and in which the intake of salt water to be desalinated is controlled by a static automatic control system. The apparatus using solar energy comprises a main insulated container with a subsidiary pre-heating container next to it; the main container is covered with a transparent cover serving as a selective filter to provide the "greenhouse effect" and also as a condensation surface for water vapour. This transparent cover incorporates a hollow space, for example, by making the cover double skinned. The hollow space forms part of a siphon which automatically regulates the water levels, transferring salt water from a pre-heating container to the main container as the level in the main container falls, owing to loss by evaporation leading to condensation and withdrawal of the desalinated water. The hollow part of the transparent cover thus serves also to pre-heat the incoming salt water with the heat lost upon condensation by the vapour within the main container.
Sources of pollution	R.D. Johnson, R.L. Jones, T.D. Hinesly and D.J. David, "Selected chemical characteristics of soils, forages and drainage water from the sewage farm serving Melbourne, Australia". Available from the National Technical Information Service, Springfield, Virginia 22161, as	A review of the chemical characteristics of sewage, soils, forage and drainage water from the Werribee Farm land application municipal waste-water treatment system at Melbourne, Australia, was performed by the Army Corps of Engineers. The raw sewage reaching the farm was highly concentrated because of the low water usage in the area and contained about 1,788 ppm total solids, 756 ppm volatile solids, 473 ppm suspended solids, 67.9 ppm total nitrogen, 34.5 ppm total phos-

Subject	*Source*	*Description*
	No. AD-A019 586 (January 1974)	phorus, 654 ppm Cl and 578 ppm BOD. Treatment is provided primarily by land filtration in the summer, with additional treatment provided by overland flow and oxidation ponds; the average flow is about 144 mgd. Soils consist of red-brown silty clay loam, calciferous silty clay and sand. The study showed soils had increased levels of N, C and P and higher Ca/Mg ratios; soil K was unchanged or reduced. Total soil contents of all trace elements were increased by waste-water irrigation; Zn levels were significantly high. Forage contained increased levels of N, P, K and Na but reduced amounts of Mn. Drainage waters had lower N and P concentrations than secondary effluents from biological treatment plants and about the same concentration levels of several heavy metals. The treatment farm has been in operation since 1897.
Sources of pollution	P.G. Whitehead, "Water quality models for waste water management", in *Effects of Urbanization on the Hydrological Regime and on Water Quality*, Proceedings of the Amsterdam Symposium, October 1977	A methodology is proposed for evaluating the impact of effluent on the aquatic environment and for the development of management strategies for the planning and control of waste-water systems. This particular approach considers the dynamic behaviour of the river system and relates time varying upstream influents to downstream water quality using simple, low-order but robust models of water quality. Identification and estimation problems are investigated using recursive algorithms of time series analysis and practical applications are considered for an artificial aeration scheme on the River Cam and a probabilistic assessment of the impact of effluent from the new town of Milton Keynes in the United Kingdom.
Streamflow and runoff	"Flood hazard analyses: North Fork Rush Creek, Hennepin County, Minnesota", Minnesota Department of Natural Resources and the Elm Creek Management and Protection Commission, Minnesota (December 1977), p. 24	This report describes the flood hazard potential of North Fork Rush Creek, of the Elm Creek basin in south-eastern Minnesota. Located just north-west of the Minneapolis-St. Paul (Twin Cities) metropolitan area, the Elm Creek basin last experienced flooding in April 1965 from snowmelt coupled with rain. Approximately 25.3 square miles in area, the drainage basin consists mainly of agricultural lands. Owing to its proximity to the Twin Cities, the Basin is experiencing rapid urbanization. Historical flood data are limited; the 1965 flood appears to have been of slightly less intensity than the 100-year flood. There are no gauging stations in the study area. Eleven of the 19 road crossings over the creek in the study area would be overtopped by the 100-year flood. At the mouth of the creek, the 100-year flood would discharge 610 cubic feet per second (cfs), while the 500-year flood would discharge 745 cfs. The area's flood-plain management programme contains some zoning ordinances, but the report recommends a more comprehensive programme. Flood-plain management techniques and tools are presented. The report proposes that the basin be divided into three zones: (*a*) secondary flood area, where construction of buildings with basements above flood protection elevation is allowed; (*b*) flood fringe area,

Subject	*Source*	*Description*
		where no basements would be constructed; and (*c*) floodway, where none except possibly recreational uses would be allowed.
Streamflow and runoff	"Special flood hazard information report: Deer Creek, Glenrock, Wyoming", City of Glenrock, Wyoming (December 1971), p. 20	The Deer Creek basin is a 213-square mile area in east central Wyoming. The drainage basin is 30 miles long and up to 7 miles wide. Two major tributaries of Deer Creek are West Fork Deer Creek in the central basin and Little Deer Creek in the lower basin. About a third of the flood plain in the study area is covered with trees, and the main use of the plain is for livestock production. Oil wells are located in the flood plain. Some urban development is located in the flood plain around the city of Glenrock. Flood records were obtained from a gauging station in operation since 1924. Floods are caused by heavy spring and summer rainfall, sometimes augmented by snowmelt. The largest flood occurred in June 1970, discharging 14,200 cfs. Damages came close to $US 1,000,000. Another large flood in May 1965 discharged 12,800 cfs. After an occurrence of the intermediate regional flood (IRF), the Deer Creek surface area would swell to more than eight times its normal width and add up to ten feet to its depth. The standard project flood (SPF) would swell the stream an additional 10-15 per cent in area and in depth. IRF would have an estimated discharge of 12,700 cfs, while SPF would have an estimated discharge of 31,500 cfs. The study concludes that future development should not be located in the flood plain. Fast peaking of floods at Glenrock presents a hazard. This study is intended to identify flood hazard areas for the benefit of planning officials.
Streamflow and runoff	P.H. Weiner, "Water, water everywhere: power flows in the lower Rio Grande valley", *Detroit University Journal of Urban Law*, vol. 54, No. 4 (Summer, 1977), pp. 743-63	The latest eipsode in the lower Rio Grande river valley's century-long struggle over scarce water resources is chronicled. Chief among the districts authorized by Texas statutes are water control and improvement districts (WCIDs) now governed by chapter 51 of the Texas Water Code. Despite the versatility of WCIDs, they have been used in the lower valley almost exclusively for irrigation, and *chicano colonias* have been excluded from their membership. The solution was the rural water supply corporation. Despite its drawbacks, the Military Highway Supply Corporation was created to obtain water rights for *colonias* that needed them, to contract with existing facilities and to construct delivery systems for each *colonia*. There followed a legal battle to gain power in the districts through the election of directors. It was held that: the State had exclusive power to determine the boundaries of its political subdivisions; that the discrimination by the district was between urban and non-urban property owners and not by race; and that notice by publication was acceptable. Power remains concentrated in the hands of Anglo growers, who have both the will and the ability to wield it.

Subject	*Source*	*Description*
Ultimate disposal of wastes	"Evaluation of land applications systems". Available from the National Technical Information Service, Springfield, Virginia 22161, as No. PB-257 440 (1975), p. 194	Procedures are outlined for EPA personnel for the application of municipal waste water to land. An evaluation checklist and relative background information are provided. Sections are included on the facilities plan, design plans and specifications, and operation and maintenance manuals. The first section provides a thorough evaluation of land application alternatives and the preparation of a detailed facilities plan as well as evaluations of potential sites, land application alternatives, design considerations and environmental factors. The second section describes procedures for evaluating design plans and specifications, with emphasis on the agreement of the facilities design with the conditions of the particular site. The third section outlines special considerations for land application systems with respect to operating procedures, monitoring requirements and impact control.
Use of water of imparied quality	A.M. Balba, "Evaluation of changes in the Nile water composition resulting from the Aswan High Dam", *Journal of Environmental Quality*, vol. 8, No. 2 (April-June 1979), pp. 153-156	The composition of Nile river water was examined to show the effect of the Aswan High Dam on the fertility and salinity of the water for irrigation. The Nile water contains about 110,000,000 metric tons/year of suspended materials as it crosses the Egyptian border. Before the Aswan High Dam was constructed, 24,000,000 metric tons/year of solids were deposited, mainly on the Egyptian flood plains. After the dam was finished, only 2,100,000 metric tons/year of solids were present in the Nile water to be deposited on the Egyptian soils; the remainder, 21,900,000 metric tons/year of solids, settled in Lake Nasser. The loss of nutrients in the sediments which settled in Lake Nasser and the gain in soluble cations which resulted from construction of the Dam were calculated from sediments and water analyses. The loss of 12,000 metric tons/year of sediment N is probably not significant for Egyptian agriculture. The loss of P, including a maximum of 6,000 metric tons/year of soluble P, will probably require a significant increase in the use of P fertilizers. The quality of the Nile water for irrigation, as determined by values for electrical conductivity, sodium adsorption ratio, adjusted sodium adsorption ratio, residual carbonate and pHc. did not change significantly after construction of the Dam.
Waste treatment processes	O.T. Bolotina, "The means and problems of preventing pollution of surface waters by waste water from cities", in *Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality*, Proceedings of the Amsterdam Symposium, October 1977	A most urgent task for water conservation is to stop the pollution of water bodies by waste water discharged by sewers from large industrial cities. Currently, industrial wastes are prevalent in urban waste water, but a substantial decrease in their quantity is expected. Also, the volume of domestic waste water is expected to increase as more houses are modernized. By analysing the present situation and evaluating future trends, the joint treatment of domestic and industrial waste water is recommended. The processes responsible for the quality of water bodies depend on various factors, the decisive one being the discharge of urban waste water. It is essential for pollution control to start at the

Subject	*Source*	*Description*
		sources of the pollutants. The observance of standards established for all stages of the collection and treatment of waste waters must be strictly supervised. For future techniques, the classical, complete biological treatment of urban waste waters will be adequate to preserve the quality of water in lakes and reservoirs. Supplementary treatment by filtration through sand is perhaps necessary in some cases. The extraction of biological substances will be necessary for large flows of waste water with high concentrations of pollutants. A strict observation of established standards for the composition of industrial effluents which discharge into the sewerage network is imperative. For self-purification of water bodies, the waste waters discharged into them must first be biologically treated.
Waste treatment processes	L.E. Eckley, L. Cantor and G. Reid, "Operation of stabilization ponds in a tropical area". Available from the National Technical Information Service, Springfield, Virginia 22161, as No. AD-B015 604 (1974)	A series of phase studies investigated the use of single and multiple stabilization ponds for the treatment of secondary waste waters as a simple and inexpensive method of treatment in tropical regions. Initial studies established single ponds 4 to 6 feet in depth; subsequent studies evaluated multiple pond configurations providing anaerobic and aerobic modes of operation. The optimum pond configuration for treating the waste waters was found to be a three-pond system, operating in the order of an anaerobic pond, a facultative pond and a maturation pond. This system reduced BOD by 75 per cent, COD by 60 per cent, organic and ammonia nitrogen by 58 per cent, and *E coli* by 91 per cent; orthophosphates and nitrates increased in this and most other systems studied. The maximum loading for this system was 150 lb BOD/acre/day. Design effluent removals based on influent content, influent-effluent flow, and meteorological considerations were developed with multiple regression analyses. Studies were also conducted on *S typhi* survival in the ponds, shock loadings of selected pesticides, mosquito control and sludge build-up.
Waste treatment processes	"Pollution from agricultural and food industries", *Energy*, vol. 4, No. 4 (April/May 1978), pp. 20-21	The volume and quantity of pollution from the agricultural and food industries varies according to the type of activity, production process, tonnages involved, the season and even the day and time of day. The effluent, essentially organic in composition often has a high DCO and DBO5 content. The known waste treatments must be adapted to the individual segments of the agricultural and foodstuffs industries. Water recycling techniques have been intensively studied in France in recent years and a number of plants are effectively treating waste water for internal reuse. The Adour-Garbonne basin authorities report a 60 per cent reduction in the amount of water to be treated from a cooked meat and vegetable preserving plant. The increase of large-scale food production units over the last 15 years has necessitated the construction of purification stations for their effluents. These purification stations generally utilize microbial degradation in the form of aerobic treatment or anaero-

Subject	Source	Description
		bic digestion. The performance of these stations varies with the material and the number of recycling operations used; efficiency ranges between 40 and 65 per cent for heavy and medium loads. Difficulties encountered in separating the bacterial agglomerates of processed water by simple decantation are known as "festering expansion" of the activated sludge. Research on these difficulties and the techniques of operating purification stations has been carried out by the Institut National de la Recherche Agronomique.
Waste treatment processes	B.L. Seabrook, "Land application of waste water in Australia, The Werribee Farm system, Melbourne, Victoria". Available from the National Technical Information Service, Springfield, Virginia 22161, as No. PB-257 454 (May 1975)	The Werribee Farm at Melbourne, Australia, treats an average daily municipal waste-water flow of 150 mgd, with land treatment comprising land filtration, sedimentation, overland flow and lagooning. The treatment system, in operation since 1897, cost about $US 1.53 *per capita* to operate in 1974. The land treatment system treats about 95 per cent of the sewage from a population of 1,880,000. The farm incorporates a total area of about 27,000 acres and provides grazing land for 20,000 cattle and 10,000 sheep which have a net return of $US 75,000 per annum. About 38 per cent of the sewage is treated by crop irrigation, 39 per cent by overland flow and 23 per cent by oxidation lagoons. A conventional secondary mechanical treatment plant was constructed to handle about 45 per cent of the sewage load to prevent overloading of the land treatment system.
Waste treatment processes	"When water is threatened", *Civil Engineering Contractor*, vol. 12, No. 12 (September 1978), pp. 37 and 39	Water development is a carefully planned priority in Rhodesia (now Zimbabwe), a small land-locked country where the major rivers are contiguous to alien lands, or arise in one territory and flow through the country into another. The country's water legislation is based on maintaining full control over the development of water resources for its own benefit, while respecting neighbouring interests by providing for consultation with other riparian States for planned development. The annual population growth rate of 3.6 per cent necessitates careful planning, with catchment planning as the objective. Water resources are derived entirely from the annual rainfall, which occurs during a few months. The existing 7,200 major and lesser dams provide a storage capacity of 3.6 billion cubic meters. Long-term hydrological data are being obtained from 470 recorder installations in the main rivers. Large dam sites are being developed to the optimum storage capacity within the limitations of the physical features of the site and catchment yield. Currently, the Ministry of Water Development has selected 310 large dam sites and developed plans for 85; 90 large dams have already been contructed. Storage capacity requirements for the year 2000 have been forecast at approximately 16 billion cubic meters, or about half the optimum storage capacity required to develop the full estimated potential yield of the country's water resources. The country's

Subject	*Source*	*Description*
		maximum utilization of storage/yield is 50 per cent, compared with 80 to 100 per cent for the United States, Australia and Iraq.
Waste treatment processes	W. Whipple, Jr., "Advantages and disadvantages of regional sewerage systems", *Water Resources Bulletin*, vol. 14, No. 6 (December 1978), pp. 1449-1456	A few years ago, many water quality administrators were convinced that large regional sewerage systems, consisting of one large treatment plant and long trunk sewers extending to various communities, represented the only efficient and economical means of ensuring water quality control. In communities favouring rapid development, the provision of sewer service and encouragement of development of new centres along the trunk sewers offered an additional advantage. More recently, quite different points of view have been arising in certain areas. In parts of New Jersey, strong environmental and community resistance has arisen to proposed central plant-trunk sewer systems. The facilitation of new development along the trunk sewers is viewed as a menace by townships not wanting intensive development of these areas. The diversion of effluent flows to trunk sewers rather than septic tanks would dry up the streams which water quality programmes are supposed to protect. Both sides to the controversy have mobilized engineering, environmental, economic and legal expertise and some critical policy issues have developed. Reconsideration of regional sewerage management and particularly trunk sewer policy is required. The decision as to extent of sewerage service areas involves complex and sensitive planning issues. Because of potential conflicts of interest, such decisions should not be left to staffs of sewerage authorities and their design engineers.
Water demand	F.A. van Duuren, "Re-use: the essential element in water utilization", *Veldtrust* (Autumn 1978), pp. 6-7	A systems approach to the efficient utilization of available water supplies in South Africa is essential in preventing a potential water shortage. Because any use of water degrades it, its quality must be reviewed and quality requirements of subsequent reuse must be critically assessed. At the current population level of 24 million, the domestic sector uses 7 per cent of the available water supply, industry uses 18 per cent and agricultural irrigation uses the remaining 75 per cent. When the population reaches 50 million, domestic use is projected to be at 15 per cent, industry at 45 per cent and irrigation at 40 per cent. Since less than half of the water is used consumptively by the domestic sector, and only a small portion is used consumptively by industry, and virtually all agricultural use is consumptive, it is concluded that irrigation should not be allowed first draught on available water supplies. In urban perimeters where domestic effluent quality and the required quality of irrigation are equal, irrigation has become a secondary user of domestic effluent. Certain industries can also use domestic effluents. At the end of the century, the domestic sector will be the smallest consumer; therefore, it should be apportioned prime use of available supplies. Planned reuse of water in industry in South Africa is very extensive.

Subject	*Source*	*Description*
		The pulp and paper industry at Springs is an outstanding example of reuse of urban effluent. Its oxygen bleach process limits the addition of dissolved solids and thus enhances reuse of water.
Water law and institutions	G.L. Finnell, Jr., "Coastal land management: an introduction", *American Bar Foundation Research Journal*, vol. 1978, No. 2 (Spring 1978), pp. 153-67	During the 1970s, the coastal zone, that ecologically unique area where sea and land meet and strongly influence each other, has become a principal laboratory for experiments in new land management techniques in the United States. Disputes over coastal land use raise important questions as to the interaction between the individual and government, and the interrelationships among local, State and national governments. Although the federal government has always played a major role in regulation of coastal activities, until recently this role was restricted mainly to regulation of activities affecting navigable waters. Today, the trend in coastal land management is not towards federal pre-emption of State and local authority, but towards "co-operative federalism". State legislatures must take the lead in designing coastal land management programmes. A State's coastal land planning process should be co-ordinated, to the maximum degree feasible, with other State programmes for transportation, energy and water resource planning. State and local governments that resist the enactment and implementation of concurrent and co-operative regulatory programmes are probably doing their citizens a serious disservice.
Water law and institutions	"Unnecessary and harmful levels of domestic sewage chlorination should be stopped". Available from the National Technical Information Service, Springfield, Virginia 22161, as No. PB-271 288 (30 August 1977), p. 36	Chlorine discharges by municipal sewage treatment plants sometimes exceed levels safe for the aquatic environment. Except for the chlorine needed to protect areas of shellfish harvesting or of unrestricted irrigation with sewage, the public health benefits from widespread use of sewage chlorination are minimal. The federal General Accounting Office (GAO) recommends that EPA should: (*a*) revise its water quality criteria regarding the bacterial standard for swimmable waters, recognize seasonal variations and delineate those circumstances where sewage chlorination is needed to protect public health; (*b*) include chlorine residual limitations in all national pollutant discharge elimination system permits for sewage treatment plants and all industrial discharges of chlorinated effluents; (*c*) lower chlorine residual limitations in power-plant effluents; (*d*) require regional offices or States to tailor permits to ensure the use of chlorine testing and operating equipment which would improve chlorination efficiency; and (*e*) incorporate rapid, thorough initial mixing and flow-proportional dosage adjustment into new plant construction review criteria. GAO also recommends that Congress should amend the 1972 Federal Water Pollution Control Act Amendments to permit exceptions to the national goal of swimmable waters to recognize those situations where waters are unswimmable for other reasons.

Subject	*Source*	*Description*
Water in soils	B.G. Donnelly, "Evidence of fish survival during habitat dessication in Rhodesia", *Journal of the Limnological Society of Southern Africa*, vol. 4, No. 1 (July 1978), pp. 75-76	From March onwards, many Rhodesian rivers begin to dry out, leaving a dry sandy river-bed apparently devoid of fish. Data are reported from 14 observations, which suggest a behavioural adaptation by *S mossambicus, Clarias gariepinus* and *Engraulicypris brevianalis* which allows them to survive when the rivers dry out. The fish may be able to burrow into wet sand and stay alive for several months by maintaining contact with the subsurface water table. During excavations of the dry sandy river-beds fish have been found in the sand up to a depth of 6 m. Future research investigations are recommended concerning the oxygen values at the depth where fish are found, and the acclimation by these fish to long periods of complete darkness, little movement and no food.
Water treatment and quality alteration	B. Whitehead, "Iodine for disinfection", *Canadian Water Well*, vol. 5, No. 2 (May 1979), pp. 9-10	Iodine has been used to sterilize water since the early 1900s. Until recently, its use has been restricted to emergency or periodic use. Prolonged use of iodine was shown to have no adverse effects and currently it is being used increasingly for treatment of individual water supplies. Iodine treatment systems can use iodine crystals on a complexed iodine liquid. The concentration of iodine and the contact time required for disinfection is temperature dependent. Under fluctuating consumption conditions, the temperature in the contact tank will vary. Therefore, tank volume and the minimum concentration of iodine must be based on the minimum water temperature. Iodine up to 1.5 mg/l imparts no observable taste or odour. Iodine is relatively inert with respect to ammonia and other organics, so that iodamines are not formed in the same way as chloramines (potential carcinogens) are formed by chlorination. High organic contents in water creating high iodine demands may, however, preclude the use of iodine and therefore any potential negative effects of iodination. There is, however, no residual to maintain the bacterial integrity of the system. Long-term physiological effects of iodination are as yet uncertain, particularly in children, and more research is needed.
Water yield improvement	"Final environmental statement: Project Skywater, a programme in precipitation management", vol. I. Available from the National Technical Information Service, Springfield, Virginia 22161, as No. PB-273 294, (25 October 1977)	The programmes, purpose, scope and environmental impacts of Project Skywater, a research programme in cloud seeding for enhanced precipitation conducted by the Bureau of Reclamation, are presented in a final environmental statement. The research cloud-seeding programme is designed to remove scientific doubt and develop the required technology to make cloud seeding scientifically sound and socially acceptable as a water management tool. The research is not expected to have significantly adverse impacts, and any effect on avalanches and snow removal costs will probably be undetectable. Application of this technology could increase high forest and alpine seasonal snowparts up to about 15 per cent and lengthen snow cover in areas prone to drifting by a week. Runoff in the high country would be increased about 20 per cent and local water

Subject	Source	Description
		quality should improve. The carrying capacity of elk ranges could be decreased in a few locations at an undetectable level. A possible 10 per cent increase in summer convective rainfall would result in minor, local increases in humidity, runoff and ground-water levels. Although erosion would most likely decrease on vegetated lands, range converted to cropland might become more subject to erosion. For each potential impact, two numerical ratings are given: one applicable to the research programme, the other applicable if the technology being developed is applied in a long-term continuous and widespread mode.

كيفية الحصول على منشورات الامم المتحدة

يمكن الحصول على منشورات الامم المتحدة من المكتبات ودور التوزيع في جميع انحاء العالم . استعلم عنها من المكتبة التي تتعامل معها أو اكتب الى : الامم المتحدة ،قسم البيع في نيويورك او في جنيف .

如何购取联合国出版物

联合国出版物在全世界各地的书店和经销处均有发售。请向书店询问或写信到纽约或日内瓦的联合国销售组。

HOW TO OBTAIN UNITED NATIONS PUBLICATIONS

United Nations publications may be obtained from bookstores and distributors throughout the world. Consult your bookstore or write to: United Nations, Sales Section, New York or Geneva.

COMMENT SE PROCURER LES PUBLICATIONS DES NATIONS UNIES

Les publications des Nations Unies sont en vente dans les librairies et les agences dépositaires du monde entier. Informez-vous auprès de votre libraire ou adressez-vous à : Nations Unies, Section des ventes, New York ou Genève.

КАК ПОЛУЧИТЬ ИЗДАНИЯ ОРГАНИЗАЦИИ ОБЪЕДИНЕННЫХ НАЦИЙ

Издания Организации Объединенных Наций можно купить в книжных магазинах и агентствах во всех районах мира. Наводите справки об изданиях в вашем книжном магазине или пишите по адресу: Организация Объединенных Наций, Секция по продаже изданий, Нью-Йорк или Женева.

COMO CONSEGUIR PUBLICACIONES DE LAS NACIONES UNIDAS

Las publicaciones de las Naciones Unidas están en venta en librerías y casas distribuidoras en todas partes del mundo. Consulte a su librero o diríjase a: Naciones Unidas, Sección de Ventas, Nueva York o Ginebra.

LITHO IN U.N. THAILAND